Edited by John Dixon, Dennis P. Garrity, Jean-Marc Boffa, Timothy Olalekan Williams, Tilahun Amede
with Christopher Auricht, Rosemary Lott and George Mburathi

Farming Systems and Food Security in Africa

Priorities for science and policy under global change

Farming Systems and Food Security in Africa

Knowledge of Africa's complex farming systems, set in their socio-economic and environmental context, is an essential ingredient to developing effective strategies for improving food and nutrition security.

This book systematically and comprehensively describes the characteristics, trends, drivers of change and strategic priorities for each of Africa's fifteen farming systems and their main subsystems. It shows how a farming systems perspective can be used to identify pathways to household food security and poverty reduction, and how strategic interventions may need to differ from one farming system to another. In the analysis, emphasis is placed on understanding farming systems drivers of change, trends and strategic priorities for science and policy.

Illustrated with full-colour maps and photographs throughout, the volume provides a comprehensive and insightful analysis of Africa's farming systems and pathways for the future to improve food and nutrition security. The book is an essential follow-up to the seminal work *Farming Systems and Poverty* by Dixon and colleagues for the Food and Agriculture Organization (FAO) of the United Nations and the World Bank, published in 2001.

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Preface

Economic growth in Africa accelerated in the new millennium, enhancing confidence in the continent's future. Positive developments have taken place in the liberalization of trade and markets, in the strengthening of institutions and policies, and in investments in human and social capital and infrastructure. However, the growth has not trickled down to the large number of rural people experiencing chronic or crisis-driven hunger and poverty. Thus, Africa has had a larger proportion of extreme poor than any other region of the world.

Most of Africa's poor are rural and most rely largely on crops, livestock, trees and fish – along with off-farm income – for their livelihoods. The improvement of agriculture, particularly smallholder farming systems, is fundamental to overcoming the problems of rural poverty and lagging rural economies. The African rural development context is unique and diverse, in its geography, agro-ecology, history, politics and culture. National and regional decision makers face the challenge of identifying the best agricultural and rural development opportunities with the greatest impact on food security, livelihoods and economic growth. Experience has shown that policy and investment decisions must be better grounded in local context-specific analyses, incorporating multi-stakeholder and systems approaches focused on the livelihood strategies and opportunities of farm men and women. The value of targeting technologies and policies to different farming systems has been recognized in the Science Agenda of the Forum for Agricultural Research in Africa (FARA).

At the opening of the new millennium an FAO/World Bank analysis was published that examined rural development opportunities over the period from 2000 to 2015 from the perspective of farm households in major farming systems of the developing world (Dixon et al. 2001; www.fao.org/farmingsystems/). The analysis classified and mapped farming systems, including those of Africa, examined the drivers of change for the 2000–2015 period and identified strategic priorities for each system. This farming system framework and analysis has proved to be valuable for targeting and prioritizing agricultural research and development initiatives and has been used repeatedly – for example, by the InterAcademy Council report on Africa, the Millennium Villages Project, the CGIAR Collaborative Research Programs, and others.

Given the major changes in African agricultural opportunities, it was time for an update of the 2000 FAO/World Bank analysis of African farming systems looking forward from 2015 to 2030. Since 2000 the African population has increased by a third, dynamism has returned to many African economies and regional agricultural research and development organizations have generated and disseminated many new varieties

and practices – but farm household vulnerability and international market volatility have increased. The Australian Centre for International Agricultural Research supported an update, with assistance and guidance from the New Partnership for Africa's Development, the United Nations Economic Commission for Africa, the CGIAR, the World Bank, and the Food and Agricultural Organization.

The work was coordinated by the World Agroforestry Centre (ICRAF) in Nairobi. More than 60 scientists and development professionals, working in multi-disciplinary teams, assessed constraints, trends and strategic interventions in the 15 major farming systems across the continent. The analysis integrated key recent strategic reports and a wealth of expert knowledge and spatial data – including natural resource, production, infrastructural and nutritional information from FAO, World Bank, CGIAR, International Institute for Applied Systems Analysis (IIASA) and other sources.

The resulting book provides a unique systematic, forward-looking, compendium of continent-wide farming system assessments and databases for agribusiness, policy makers and science leaders. The document will undoubtedly be a fundamental guide for years to come for prioritization and targeting of public and private investments to deliver food and nutrition security and rural transformation in Africa.

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Abbreviations

Acronyms

ACIAR	Australian Centre for International Agricultural Research
ADLI	Agriculture Development-Led Industrialization
ADMARC	Agricultural Development and Marketing Corporation (Malawi)
AEZ	Agroecological Zone
AfDB	African Development Bank
AGRA	Alliance for a Green Revolution in Africa
AIDS	Acquired Immune Deficiency Syndrome
APP	Africa Progress Panel
ASAL	Arid and Semi-arid Lands
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ATA	Agricultural Transformation Agency (Ethiopia)
AU	African Union
BEAT	Barefoot Education for Afrika Trust (Zimbabwe)
CA	Conservation Agriculture
CAADP	Comprehensive Africa Agriculture Development Programme
CABI	Centre for Agriculture and Bioscience International
CAMES	Maître de Recherche en Sciences Agronomiques
CARE	Christian Action Research and Education
CASI	Conservation Agriculture-based Sustainable Intensification
CBPP	Contagious bovine pleuropneumonia
CCARDESA	Centre for Coordination of Agricultural Research and Development for Southern Africa
CCPP	Contagious caprine pleuropneumonia
CGIAR	Consultative Group for International Agricultural Research
CIAT	International Center for Tropical Agriculture (Centro Internacional de Agricultura Tropical)
CIESIN	Center for International Earth Science Information Network
CIFOR	Center for International Forestry Research
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	French Agricultural Research Centre for International Development (Centre de Coopération Internationale en Recherche Agronomique pour le Développement)

CO ₂	Carbon dioxide
COMESA	Common Market for Eastern and Southern Africa
COOPAC	Coopérative pour la Promotion des Activités Café (Rwanda)
CORAF	Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricole
CRIG	Cocoa Research Institute of Ghana
CSA	Climate-smart agriculture
CTA	Centre Technique de Coopération Agricole et Rurale
DAP	Di-ammonium Phosphate
DRC	Democratic Republic of Congo
DTMA	Drought Tolerant Maize for Africa
EAC	East African Community
EAHB	East African Highland Banana
ECF	East Coast Fever
EIAR	Ethiopian Institute of Agricultural Research
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Statistical Databases (United Nations)
FARA	Forum for Agricultural Research in Africa
FASID	Foundation for Advanced Studies on International Development
FBFS	Fish-based farming system
FDI	Foreign direct investment
FEWS-NET	Famine Early Warning Systems Network
FIPS	Farm Input Promotions Africa Ltd
FMD	Foot and mouth disease
FMNR	Farmer-Managed Natural Regeneration
FRS	Forest rent subsystem of the tree crop farming system
FSA	Farming Systems Approach
FSR&D	Farming Systems Research and Development
GADP	Gross Agricultural Domestic Product
GAEZ	Global Agroecological Zone
GDP	Gross Domestic Product
GET	Geoscience Environment Toulouse
GHG	Greenhouse gas
GHI	Global Hunger Index
GIS	Geographic Information System
GIZ	German Corporation for International Cooperation
GNI	Gross National Income
GWUE	Green Water Use Efficiency
IAGU	Institut Africain de Gestion Urbaine
IBLI	Index Based Livestock Insurance
ICARDA	International Center for Agricultural Research in the Dry Areas
ICIMOD	International Centre for Integrated Mountain Development
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information Communication Technology
IDRC	International Development Research Centre
IFAD	International Fund for Agricultural Development

IFPRI	International Food Policy Research Institute
IGAD	Inter-Governmental Authority on Development
IIASA	International Institute for Applied Systems Analysis
IITA	International Institute for Tropical Agriculture
ILRI	International Livestock Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
INM	Integrated Nutrient Management
INTSORTMIL	International Sorghum and Millet Collaborative Research Support Program
IPM	Integrated Pest Management
IPS	Industrial plantation subsystem of the tree crop farming system
IRD	French National Research Institute for Sustainable Development (Institut de Recherche pour le Développement)
IRDP	Integrated Rural Development Program
ISFM	Integrated Soil Fertility Management
ISRIC	World Soil Information Centre (also International Soil Reference and Information Centre)
IT	Information Technology
ITC	Center for International Earth Science Information
IWAD	Integrated Water and Agricultural Development Ghana Limited
IWMI	International Water Management Institute
JRC	Joint Research Centre
KARI	Kenya Agricultural Research Institute
LER	Land Equivalent Ratio
LGP	Length of Growing Period
LSIFS	Large-scale irrigated farming system
LSLA	Large-scale land acquisition
MENA	Middle East and North Africa region
MPA	Marine Protected Area
M-PESA	M-Pesa (M for mobile, pesa is Swahili for money) is a mobile phone-based money transfer, financing and microfinancing service
N	Nitrogen
NA	North Africa
NALEP	National Agriculture and Livestock Extension Program (Kenya)
NARI	National Agricultural Research Institute
NARS	National Agricultural Research System
NEFSALF	Nairobi and Environs Food Security, Agriculture and Livestock Forum
NEPAD	New Partnership for Africa's Development
NGO	Non-Governmental Organization
NPK	Nitrogen-Phosphorous-Potassium
NRCRI	National Root Crops Research Institute (Nigeria)
NRM	Natural Resource Management
NTFP	Non-Timber Forest Product
NUANCES	Nutrient Use in Animal and Cropping systems – Efficiencies and Scales
NVDI	Normalized Difference Vegetation Index
ODA	Overseas Development Assistance

ODI	Overseas Development Institute (UK)
OECD	Organization for Economic Cooperation and Development
OPV	Open Pollinated Variety
P	Phosphorous
P/PET	Precipitation /Potential Evapotranspiration
PEN	Poverty and Environment Network
PPP	Public-Private Partnership
PPP	Purchasing Power Parity
PPR	Pestes des petits ruminants
PRSP	Poverty Reduction Strategy Programme
R4D	Research for Development
R&D	Research and Development
RAB	Rwanda Agricultural Board
REDD+	Reducing emissions from deforestation and forest degradation in developing countries
ReSAKSS	Regional Strategic Analysis and Knowledge Support System
RinD	Research in Development
RNFE	Rural Non-Farm Economy
RUAF	Resource Centres on Urban Agriculture and Food Security
RUE	Rain Use Efficiency
S3A	Science Agenda for Agriculture in Africa
SADC	Southern Africa Development Community
SAP	Structural Adjustment Program
SAPEP	Smallholder Agricultural Productivity Enhancement Program (Burkina Faso)
SDG	Sustainable Development Goal
SIDS	Small Island Developing States
SIMLESA	Sustainable Intensification of Maize Legume Cropping Systems for Food Security in Eastern and Southern Africa
SIP	Sustainable Intensification Practice
SIS	Smallholder intensified subsystem of the tree crop farming system
SLA	Sustainable Livelihoods Approach
SNSF	Swiss National Science Foundation
SRO	Sub-Regional Organization
SSA	sub-Saharan Africa
STCP	Sustainable Tree Crops Program (West Africa)
TAPRA	Tegemeo Agricultural Policy Research and Analysis (Kenya)
TFP	Total Factor Productivity
TLU	Tropical Livestock Unit
UEMOA	West African Economic and Monetary Union
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Program
UNECA	United Nations Economic Commission for Africa
UPA	Urban and peri-urban agriculture
UPUFS	Urban and peri-urban farming system
USA	United States of America
USAID	United States Agency for International Development (USA)

WECARD	West and Central African Council for Agricultural Research and Development
WFP	World Food Program
WHO	World Health Organization
WUA	Water Users' Association
WWF	World Wildlife Fund

Abbreviations (units)

%, pc	percentage
BP	before present
CV, c.v.	Coefficient of Variation
cm	centimetre
d	day
g	gram
ha	hectare
h, hr	hour
incl	including
k	thousand
kcal	kilocalorie
kg	kilogram
km, km ²	kilometre, square kilometre
mm, m, m ³	millimetre, metre, cubic metre
M (m), Mt	million, million tonne
MW	megawatt
pa	per annum
pc, per capita	per person
pop	population
USD, US\$	US dollar

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Part I

Introduction

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1 Africa through the farming systems lens

Context and approach

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Key messages

- The African continent is at a turning point, moving from unfulfilled development potential towards sustainable agricultural intensification, which must accompany and drive economic growth to alleviate poverty and improve food security.
- African agriculture is heterogeneous and dynamic. Investing in sustainable agricultural intensification requires a framework to differentiate and target different investments responsive to the needs of different farming system. Each of the 15 broad farming systems in Africa comprises millions of farm households with similar livelihood patterns and broadly similar development opportunities.
- Seven drivers operating in various combinations shape the trends and development options for each farm household and the different strategic interventions for each farming system.
- Farming systems analysis can contribute to broad-based transformation and improved food and nutrition security in several ways. Because most food insecure and hungry people reside in rural areas, effective food systems must be based on productive and resilient farming systems that integrate food consumption and production decisions, maintain diverse local diets to reduce malnutrition, yet also facilitate improved production and trading with wider markets.
- Farming system intensification tailored to local resources, crops and livestock will generally increase farm labour productivity and reduce poverty. Rural poverty reduction strategies for job creation, gender empowerment and youth entrepreneurship should reflect different livelihood patterns in each farming system.
- Analysis of farming systems, including forward and backward linkages and value-addition, can focus investments on bundles of commodities, food processing and agribusiness potential, which improve food and nutrition security for consumers and producers.
- Livelihood systems in Africa are highly vulnerable to shocks, including market volatility, climate variability and climate change. Systematic analysis of farming systems can facilitate the identification of policies and investments that target the development of sustainable and resilient farming systems.

Summary

Despite vigorous national economic growth, significant rural poverty and food insecurity persists in many African countries, despite notable national economic development since the late 2000s. About 90 per cent of Africa's poor live in rural areas and about 80 per cent derive their living from rainfed farming. Improving smallholder agriculture is now seen as fundamental to inclusive sustainable development. The African continent contains a mosaic of natural resources, human settlements and institutions which shape fifteen major farming systems, each with a characteristic mixture of trees, crops, livestock, fish and livelihoods – and particular development pathways. Within each farming system zone, the farm household systems and opportunities are shaped by seven drivers of change, notably population, natural resources and climate, energy, human capital, technologies, markets and policies. To escape poverty and improve food and income security, African farm households follow one or more of a set of strategies including intensification and diversification of production and increased off-farm income.

This book takes a unique farming system perspective on the analysis of the drivers, trends and opportunities for farm households to improve food security or escape from poverty. In this way, the book identifies strategic science, investment and policy interventions, targeted to each farming system. The book updates and deepens the sub-Saharan African (SSA) regional component of the FAO/World Bank 2001 global analysis of farming systems, and it has been carefully structured to complement rather than replace existing sectoral and regional development assessments of the African continent.

This chapter introduces the African agricultural and food security context, the farming system framework, key drivers of change and the fifteen principal farming systems in Africa.

From unfulfilled potential in Africa to sustainable development

The vision of a prosperous rural Africa, with abundant economic opportunities, sustainable use of natural resources, and an end to poverty and hunger, underpins this book.

The roots of the unfulfilled development potential of Africa lie in the stagnation of many African economies and agricultural sectors during the period from the 1970s to the 1990s – sometimes referred to as the 'lost decades'. Subsequently, most countries have emerged from stagnation and are recording impressive economic growth rates in this new millennium (Badiane and Collins 2016). By 2012, six of the ten fastest growing economies in the world were located in Africa. By 2015 the SSA region recorded a 4.4 per cent growth rate, equivalent to the average growth rate of all low- and middle-income countries. Nevertheless, agricultural sector growth is slow and the agricultural sector share, measured in Gross Domestic Product (GDP) terms, is modest, despite the land resources and agricultural population of Africa. In fact, development planners normally expect agriculture to contribute a greater share of GDP given the prevailing levels of per capita income in Africa.

In order to benefit fully from sustainable development pathways, national economic growth must be complemented by vigorous agricultural and rural development. Agriculture remains the main source of livelihoods for the rural population, which represented approximately half of the African population of nearly 1.2 billion in 2015. In contrast to other regions of the world, African farming (including pastoral, livestock, forestry

and fishing) engages two-thirds of the continent's labour force and contributes about one-third of regional GDP. Moreover, growth in farm household income generally stimulates substantial rural non-farm economic growth. However, the persistence of widespread food insecurity and rural poverty in Africa, as well as natural resource degradation, was the motivation for the analysis reported in this book.

For maximum effectiveness of agricultural development policies, investment programs and agricultural research, it is necessary to unpack the diversity of African agriculture into distinct, broad farming system zones (hereafter referred to as farming systems) and ascertain priority strategic interventions for each system. For this purpose, the constraints and opportunities are analysed and probable trajectories of development identified. Farm household income, livelihoods and food security are closely related and dependent on the nature of the farming system. The analysis recognizes the patterns of inherent diversity of farm households within any particular farming system zone and the various coping strategies employed by farm households.

This book takes a unique approach to the African drama and subsequent development, applying the farming systems perspective to the identification of priorities for agricultural policy, investment, agribusiness and technology development. The analysis complements, rather than replaces, existing assessments of African agricultural and rural development. While the geographic scope of this book is continental Africa, the emphasis lies on the complex farming systems of SSA. This book updates and deepens the SSA regional analysis of the FAO/World Bank *Farming Systems and Poverty* publication (Dixon et al. 2001). It takes into account the smallholder development successes with maize, cassava, cotton, horticulture and dairy (Abate et al. 2015; Haggblade and Hazell 2010) and the new policy settings resulting from the 2014 Malabo Declaration by African leaders to eradicate hunger by 2025 within the context of a fully transformed agriculture (Malabo Montpellier Panel 2017). The book has been written for policymakers, research leaders and investors who seek to target agricultural policy, investment plans and science priorities for maximum impact in agricultural and rural sectors.

This chapter introduces the farming systems approach used in this book, summarizes the key drivers and trends in agricultural development, and discusses the strategies used by farm households to escape poverty and improve livelihoods. The chapter also contrasts development progress in SSA with other regions, outlines the status of African food and agricultural systems, and classifies African agriculture into fifteen major farming systems. Chapter 2 outlines the methods and data used for the analysis; Chapters 3–16 list the characteristics, trends and priority interventions in each of the fifteen farming systems; and Chapters 17–19 offer a consolidation of findings, summary of ways forward and the main conclusions of the analysis.

Contrasts with other regions

Development indicators for continental Africa are often presented separately for SSA and North Africa, the latter also forming part of the Middle East and North Africa region (MENA). As shown in Table 1.1, the SSA annual economic growth rate was triple the average of MENA in 2014 and 2015, although slower than the growth rates of South Asia and East Asia. Per capita income in SSA, calculated on a purchasing power parity basis, still lags behind other regions. Conversely, per capita income in North Africa in 2014–15 was above average.

Table 1.1 Food security, economic and demographic characteristics by development region

<i>Item</i>	<i>Sub-Saharan Africa</i>	<i>North Africa and Middle East</i>	<i>South Asia</i>	<i>East Asia[#]</i>	<i>Developing countries (all)[#]</i>
Global hunger index (GHI)	32	12	29	13	22
Extreme poverty (%)*	43	3	19	7	15
GNI/cap (\$PPP)**	3,382	11,834	5,299	11,872	8,811
Economic growth (%)	4.4	1.5	6.9	6.7	4.9
Total population (million)	973	357	1,721	2,020	5,682
Population growth rate (%)	3	2	2	1	1

Source: World Bank (2015), IFPRI (2015).

Notes: Estimates are rounded. Data are from 2014 or 2015 except poverty estimates which derive from 2012.

*Extreme poverty is based on US\$1.90 per capita consumption per day (representing an update of the earlier US\$1.25 poverty level).

**Gross national income (GNI) per capita calculated at purchasing power parity.

[#]East Asia includes the Pacific. The developing countries' estimates represent all low- and middle-income countries as classified by the World Bank in 2015.

Despite the promising economic growth rate, SSA experienced greater food insecurity than developing countries overall. Moreover, about one-quarter of the SSA population were undernourished, compared with 15 per cent across all developing countries. Food and nutrition security is not only a major current challenge for SSA but also a prerequisite for sustained human development.

By poverty measures, SSA also lags behind other regions. In 2015 more than 40 per cent of the SSA population lived in extreme poverty, consuming less than US\$1.90 per day. About 90 per cent of African poor live in rural areas, although the number of urban poor is increasing with the growth of cities. Most of the rural poor scratch a living from rainfed farming, often supplemented by off-farm work. Many poor households are also food and nutritionally insecure (and vice versa). Because of extensive poverty, limited wealth is directly reinvested in farming systems. However, given agriculture is the main source of livelihood for two-thirds of African poor, boosting agriculture generally reduces national income inequality and improves food and nutrition security.

It should be noted that there has been considerable development progress in SSA since the turn of the century. The 2015 growth rate was double the growth rate during the early millennium years or the period from the 1970s to the 1990s. The global hunger index (GHI) improved from 44 in 2000 to 32 in 2015. Similarly, per capita incomes had increased and extreme poverty was reduced substantially over the period 2000 to 2015.

With a population of 1.2 billion (compared with a total population of 5.6 billion in low- and middle-income countries globally), Africa faces major development challenges and, at the same time, great opportunities. Urbanization is increasing rapidly and already approximately half the population lives in cities. Overall, the poverty, food and nutrition insecurity and income inequality stand in marked contrast to the richness of the natural resources (mineral and agricultural) and the development potential of farming systems across Africa. Arguably, the region will need more targeted investment and strengthened institutions to achieve food and nutrition security, boost rural economic growth with equity, and to achieve the Sustainable Development Goals.

Food and agriculture systems

Food and agricultural systems span the full length of food chains – from agricultural resources and inputs to food production, value chains and consumption. In Africa, food and agricultural systems are diverse and complex. In rural areas, food production and consumption are closely integrated, with many farm households producing much of their own food needs, and in African cities informal backyard and peri-urban food production is common.

Smallholder farm women and men produce a wide variety of food grains, root crops, cash crops and livestock that support diverse food and livelihood systems in different zones. Agricultural exports, including cocoa, coffee and cotton, account for about one-sixth of total exports; meanwhile cereals account for about one-tenth of total imports, albeit increasing for rice, wheat and maize. During the period from 1990 to 2015, the terms of trade for African countries worsened appreciably, which has wider policy implications.

Because food represents a large proportion of expenditure for so many low-income families (including smallholder households), persistent high and volatile food prices constrain their ability to obtain food and nourishment. Further, it also restricts their ability to purchase health, education and other essential goods and services. Malnutrition is strongly correlated with poor dietary diversity and, in farming areas, with low production diversity. Hotspots of food and nutrition insecurity and poverty often occur in areas of high population density, severe land degradation and slow agricultural growth.

The main sources of dietary energy and protein for the African population are summarized in Table 1.2 (data on specific nutrients are limited). In 2010, dietary energy was largely sourced from plants, principally cereals and starchy roots; animal products provided about one-quarter of dietary protein and also many other nutrients. The dominant crop sources were maize, sorghum, millet, cassava and wheat, with rice consumption

Table 1.2 Dietary energy and protein availability by food group

<i>Food group</i>	<i>Dietary energy (kcal/capita/day)</i>	<i>Dietary protein (g/capita/day)</i>
Plant products	2377	52.7
Animal products	217	16.1
Total	2594	68.6
<i>Breakdown by main commodity groups:</i>		
Cereals	1288	33.1
Starchy roots and tubers	329	3.9
Pulses	106	6.7
Oil seeds and oils	281	2.8
Vegetables	47	2.3
Fruit	106	1.2
Meat	87	7
Milk	88	4.5
Fish	19	3

Source: FAOSTAT (2019).

Notes: Dietary energy and protein data intake are relatively stable over the years – the above data refer to the year 2010 for Africa. The category of cereals excludes use for beer. Pulses exclude groundnuts.

Table 1.3 Sources of dietary energy and protein by agricultural commodities

<i>Commodities</i>	<i>Dietary energy (kcal/cap/day)</i>	<i>Dietary protein (g/cap/day)</i>
Maize	376	9.6
Rice	227	4.5
Sorghum	146	4.4
Millet	99	2.4
Cassava	149	1.1
Yams	79	1.3
Plantains	36	0.3
Cowpeas	—	—
Groundnuts	41	1.8
Cattle	109	5.9
Sheep and goats	14	1.1
Poultry	30	2.9
Fish	19	3.0

Source: FAOSTAT (2019).

Notes: Dietary energy and protein are indicative, referring to continental Africa. The products of the crop or the animal type (cattle meat and milk, poultry meat and eggs) are included within the respective category. Nevertheless, the listed components represent only a part of the full diets and so add up to less than the total intake.

increasing rapidly (Table 1.3). Vegetables and fruit played minor roles in the provision of energy or protein but were important sources of nutrients and minerals. While urban areas consumed significant imports of cereals, rural areas tended to be dependent on local food production.

The averages in Table 1.2 mask the wide variations within Africa in 2010, across regions and population groups. For example, dietary energy ranged from 2136 kcal per capita per day in East Africa to 3140 kcal per capita per day in North Africa; similarly, average protein intake varied from 57 grams per capita per day in East Africa to 92 grams per capita per day in North Africa (equivalent global consumption estimates are 2870 kcal per capita per day and 80 grams per capita per day). As might be expected, dietary energy and protein intakes also vary across different farming systems. Nutritional security, including the consumption of micronutrients, is of growing concern for policymakers. Fortunately, the majority of the rural population benefits from reasonably diverse diets associated with the wide range of food crops and livestock produced on most small African farms.

Through the farming systems lens

Basic concepts

The mosaic of natural resources, climate, institutions, markets and agricultural services across Africa results in diverse land use zones and patterns of farming, referred to in this book as farming systems zones, or simply farming systems. Obviously, agricultural research needs to focus on the issues and opportunities associated with current and future crop, tree and animal production, trade and consumption. Perhaps less obviously, the targeting and impact of many agricultural policies have spatial aspects which differ by agricultural zone. For example, many irrigation policies apply only to large-scale irrigation schemes

(often not small-scale irrigation), livestock water point development targets pastoralists, fertilizer policies are relevant to crop farmers, and export levies directly influence only a subset of farmers producing the export product.

At its simplest, a farming system comprises a population of farm households with similar livelihood patterns and similar development constraints and opportunities (see Box 1.1 for further explanation). The farming systems described in this book extend over large landscapes and multiple countries, and typically support tens of millions of inhabitants.

The pattern of farm enterprises and their management practices depend on the farm resource base along with the financial, social and cultural capitals. They are integral components of a farming system. Because family labour is a key resource of farm households, off-farm employment and remittances are included in the concept of the farming system. The farm enterprise patterns and their management are often influenced by local formal and informal institutions (in the sense of the well-established arrangements for management or exchange, for example competitive markets, common property resource regimes). These are also intrinsic aspects of the farming system. Household consumption is also included because, for many farm households in Africa, decisions on farm production and household consumption are interdependent.

Naturally, communities within each farming system comprise different farm household types with contrasting levels of resources, access to services and coping strategies. Distinct patterns of inter-household interaction can be associated with each farming system, for example the high social capital of traditional herders in pastoral areas, which underpins grazing and water point management, contrasts with the economic and social relationships between large commercial farms and smallholders in Southern Africa.

Systems thinking has been applied to agricultural research and development (R&D) planning and policymaking in Africa for nearly a century. The early pioneers included Allan (1965), based on analyses of Southern Africa during the 1920s, and Ruthenberg (1971), who inspired many farming systems researchers in the following decades. Of course, systems research requires a structured approach to analysing complexity (Cabrera and Cabrera 2015) and integrating knowledge from farmers, value chain entrepreneurs and from multiple scientific disciplines. Over nearly five decades of farming systems analyses, applications have gradually expanded the number of analytical variables (Norman 2002), geographic scope and purpose, notably from applied research in communities, to 'research-for-development' and now to 'research-in-development' at broader scales. Sinclair (2017) conceptualizes how such systems analysis can be applied in order to target, support and monitor impact at scale. A wide variety of methods have been applied, for example household food budgets, nutrient and feed balances, participatory appraisal and evaluation, geospatial analysis, farmer- and community-managed trials, innovation platforms and other multi-stakeholder tools. In order to inform research, extension, planners and policymakers, farming systems analysis can identify constraints and interventions or can identify, classify and characterize different types of farming systems.

In principle, farming system zonation can be undertaken at a number of different scales. Depending on the purpose, the analysis could focus on one or more of the following levels of aggregation: farm household; community (or village) and landscape; country; and region (Dixon et al. 2009). Careful consideration is required in relation to the choice of scale and acceptable levels of heterogeneity. Farming systems analysis can serve many different purposes. For national and regional policymakers and research leaders, the characterization of a modest number of broad farming systems is most useful (Garrity et al. 2017). It is important to identify key drivers and trends which shape the directions

of farming systems development. Each farming system is influenced in different ways by external forces, including predictable long-term trends (e.g. increasing population density), unpredictable variations (e.g. climatic or economic shocks) and development interventions (e.g. projects, new technologies or policy changes).

The 2001 FAO/World Bank analysis of farming systems and poverty (Dixon et al. 2001) focused on resource endowment and ‘services endowment’ (access to services including markets) as primary determinants of farming system patterns. This analysis described eight generic farming system types across the developing world, and seventy-two ‘regional’ farming systems across the six developing regions, including fifteen systems in SSA and eight systems in North Africa. Such analyses of major farming systems provide an important evidence base for agricultural policy and decisionmaking (Bwalya pers. comm.) and enables improved priority setting and accurate targeting of policies and investments. This approach supports the development of more specific policies and spatial planning of rural infrastructure, and it facilitates the monitoring of impact on different farming systems.

The above analysis influenced the update of the World Bank Rural Development Strategy and supported the prioritization and targeting of a number of CGIAR research programs. More generally, the study encouraged systems-oriented R&D projects and loans which integrated various aspects of farming including resource management, crops, trees, livestock and markets (Dixon 2006). In Africa, the study underpinned a number of subsequent assessments of African agriculture, including agricultural research and poverty reduction (Inter Academy Council 2004), and water resources development (Faures and Santini 2008). The framework was incorporated in the Science Agenda of the Forum for Agricultural Research in Africa (FARA) and was applied to support national Comprehensive African Agricultural Development Program (CAADP) agricultural investment planning in Ethiopia and Tanzania.

In this book the analyses of broad farming system zones are informed by an understanding of farm household processes, strategies and responses to the local resource, institutional and policy environment. In addition, interactions across scales are considered, for example the functionality and governance of communities, districts, watersheds, local institutions and value chains. Well-structured and functioning systems create incentives for sustainable resource management, higher productivity and improved food security, underpinning rural transformation and economy-wide growth.

Box 1.1 Definition of a farming system

A farming system is defined as a population of farm households, generally of mixed types and sizes, that as a group have broadly similar patterns of resources, livelihoods, consumption, constraints and opportunities, and for which similar bundles of development strategies and interventions would be appropriate. Often, such systems share broadly similar agroecological and market access conditions. There are inherent patterns of heterogeneity in any particular farming system, for example the interdependence between small and large farms.

Some of the major determinants of spatial differentiation in farming systems are discussed in the next subsection. The temporal differentiation or evolution of farming systems is addressed in the section on drivers and trends.

Differentiating African farming systems

Apart from some large-scale irrigation schemes, African farming systems are dominated by rainfed cropping and pastoralism, with trees and shrubs playing important roles in most areas. In SSA alone, there are nearly 100 million ha of starchy staples (cereals, roots, tubers and plantains), more than 20 million ha of cowpeas and groundnuts, as well as cash crops such as oil palm (4.6 million ha), cocoa, coffee, cotton (3 million ha each) and tobacco. Around 230 million head of cattle, 470 million head of sheep and goats, and over 1 billion poultry constitute, along with fish, the animal component of the farming systems. The majority of households manage integrated tree-crop-livestock systems with limited access to agricultural services (notably markets). Cash crops, perennials and livestock contribute importantly to food purchasing power and play critical roles in farming system function, efficiency and resilience. Distinct patterns of household production and consumption characterize each farming system.

These African farming systems are diverse, and they evolve in complex ways (Pingali et al. 1987). The two main determinants of farming systems structure and function are access to agricultural resources (or resource endowment) and access to agricultural services. In relation to the former, while there are well-watered temperate and productive highlands (and even some snow-covered mountain peaks), the vast majority of African lands are in low to mid altitudes with rainfall varying from virtually nil in the Sahara and Kalahari deserts to over 3000 mm in the highlands. The most important agroecological zones in SSA are: moist subhumid and humid zones accounting for 38 per cent of SSA land; dry subhumid areas which cover 13 per cent; and the arid and semi-arid areas which cover 43 per cent of SSA land. Most of North Africa is arid or semi-arid, with well-developed irrigation in some areas.

In relation to services endowment, there is considerable variation in the density and quality of agricultural services. African governments have begun to reinvest in agricultural services in line with the CAADP target of at least 10 per cent of public expenditure to be spent on the agricultural sector. Consequently, some farmers have benefited from improved rural transport and market infrastructure, as well as the boom in mobile phones and information infrastructure led by the private sector, while others have yet to benefit.

The rural population of approximately 0.63 billion is also distributed unevenly across the African landscape. Seventy per cent of West Africa's population lives in the moist subhumid and humid zones; in North Africa the population is concentrated in irrigated zones or semi-arid environments; in East Africa the population is distributed across several agroecological zones.

The diversity of resource endowments overlaid by a mosaic of human settlements, transport routes and markets, has shaped many different farming systems, each with its own structure and function. There might well be a greater diversity of farming systems in Africa than in any other agricultural region of the world – considering the diverse examples of highly productive banana-maize-coffee systems in the East African highlands, cereal-root crop-livestock systems in western Africa, artisanal fisheries off coastal Mozambique, nomadic pastoralism, and urban agriculture in many parts of Africa.

A number of principles guide the identification of African farming systems. First, the farming system classification must be useful for science leaders and policymakers to inform their decisions on how best to accelerate the improvement of food and nutrition security. Second, quantitative national, survey and spatial data, and key informant knowledge are equally important in delineating and analysing farming systems. Third, farming systems are characterized according to their 'central tendency' or median characteristics through

a process of pattern recognition which subsumes local heterogeneity. The main farming systems were mapped, and populations, prevalence of poverty, resource endowments, service endowments (access to markets), cultivated areas and livestock numbers were estimated from the resulting spatial analysis. Compared to the original analysis of Dixon et al. (2001), this update benefited from the availability of greater volumes of spatial data, although the breadth, consistency and compatibility of the spatial data are sometimes less than optimal. The methods and data sources are elaborated in Chapter 2.

The update analysis resulted in fifteen distinct farming systems, which are mapped (apart from the urban and peri-urban system) in Figure 1.1 and characterized in Table 1.4. Consistent with these principles, each of the farming systems is represented by a unique set of core characteristics or ‘central tendencies’ in relation to agroecology, access to services and livelihood pattern. Naturally, there is a modest degree of local heterogeneity,

Figure 1.1 The farming systems of Africa.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Note: The map refers to the year 2015; the island and the urban and peri-urban farming systems were not mapped.

including some differences in farm types and sizes, variation in soils and minor small differences in access to services and markets. The major variation is captured in defined subsystems within each farming system, described in subsequent chapters.

The approach facilitated the organization of data and expert knowledge to characterize and differentiate the agricultural populations and resource bases of each of the farming systems. Each of the systems and subsystems is characterized by a set of typical farm types with recognizable household livelihood patterns. Generally, the boundaries between systems or subsystems are gradients or soft gradations which are represented in Figure 1.1 by ‘feathered’ boundary zones. The updated and revised farming system classification for African agriculture is therefore pragmatic and differentiates farming system areas spatially, which allows presentation of the analytical results to policymakers in a practical, usable form. The classification combines similar farming systems in North Africa and SSA, for example irrigated, pastoral, and arid pastoral and oases farming systems.

In examining Figure 1.1, the two main determinants of farming systems diversity, namely resource endowment (dependent on agroecology and population density), and services endowment (access to agricultural services including markets), should be recalled. In relation to agroecology, the length of growing season (LGP, measured in days of adequate soil moisture for plant growth) is a key indicator of potential biomass productivity. One approximate indicator of services endowment is the travel time to the closest major market town, based generally on maps of rural roads. In practice, the indicator of travel time to rural market is best combined with expert knowledge on market access, because other factors, in particular supply chains and mobile phone communications, also influence market access.

Table 1.4 describes the levels of resource and service endowments and the poverty, population and farming patterns for each farming system. Most farming systems contain a substantial to high proportion of extremely poor families. Based on the absolute numbers of poor households, nearly 150 million extremely poor farming children, women and men live in the four most-populated farming systems, namely the maize mixed, agropastoral, highland perennial, and root and tuber crop farming systems. The farming systems are listed in Table 1.4 in approximate order of the estimated numbers of extremely poor farm people.

Each broad farming system listed in Table 1.4 has a set of recognizable and distinct development constraints and opportunities, and would benefit from a particular set of policies, investments and research products. Strategic interventions for each farming system are identified in the respective farming system chapters.

Farm household decisions and strategies

The core argument of this book is that an understanding of household strategies, differentiated by type of farming system, should form the basis for the design of effective agricultural policies and allocation of public resources. It is important, therefore, to distinguish the strategies of farm households from agricultural sector strategies. For example, household strategies to intensify food production, even at the risk of declining soil fertility, would conflict with Government strategies to promote sustainable land management, unless complemented by actions to promote food security or establish safety nets. Most countries contain several different farming systems, often with contrasting development constraints and opportunities. For example, a number of West African countries contain both the commercial tree crop farming system and the cereal-root

Table 1.4 Key characteristics of African farming systems

<i>Farming system</i>	<i>Agricultural population (millions)</i>	<i>Key system characteristics</i>
Maize mixed	107	Mixed farming dominated by maize with medium access to services in subhumid areas of East, Central and Southern Africa. Other livelihood sources include legumes, cassava, tobacco, cotton, cattle, shoats, poultry and off-farm work.
Agropastoral	98	Mixed crop-livestock farming found in semi-arid (medium rainfall) areas of Africa, typically with low access to services. It includes the dryland mixed farming system of North Africa, often depending on wheat, barley and sheep. In SSA the main food crops are sorghum and millet, and livestock are cattle, sheep and goats. In both cases, livelihoods include pulses, sesame, poultry and off-farm work.
Highland perennial	61	Highland mixed farming is characterized by a dominant perennial crop (banana, plantains, enset or coffee) and good market access, and is found in humid East African highlands. Other livelihoods derive from diversified cropping including maize, cassava, sweet potato, beans, cereals, livestock and poultry augmented by off-farm work.
Root and tuber crop	50	Lowland farming dominated by roots and tubers (yams, cassava) found in humid areas of West and Central Africa. Other livelihood sources include legumes, cereals and off-farm work.
Cereal-root crop mixed	43	Mixed farming with medium-high access to services dominated by at least two starchy staples (typically maize and sorghum) alongside roots and tubers (typically cassava) found in the subhumid savannah zone in West and Central Africa. Other livelihood sources include legumes, cattle and off-farm work.
Highland mixed	45	Highland mixed farming above 1700 m dominated by wheat and barley, found predominantly in subhumid north-east Africa with pockets in Southern, West and North Africa. Other livelihood sources include teff, peas, lentils, broad beans, rape, potatoes, sheep, goats, cattle, poultry and off-farm work.
Tree crop	30	Lowland farming dominated by tree crops (> 25% cash income from cocoa, coffee, oil palm or rubber) found in humid areas of West and Central Africa with good access to services. Other livelihood sources include citrus, yams, cassava, maize and off-farm work.
Pastoral	38	Extensive pastoralism (dominated by cattle), found in dry semi-arid (low rainfall) areas with poor access to services. Other livestock include camels, sheep and goats alongside limited cereal cropping, augmented by off-farm work.
Fish-based	22	Found along coasts, lakes and rivers across Africa with medium-high access to services, with fish a major livelihood. Other livelihood sources include coconuts, cashew, banana, yams, fruit, goats, poultry and off-farm work.

Forest-based	12	Lowland, heavily forested humid areas in Central Africa with low access to services and subsistence food crops (cassava, maize, beans, coco-yam and taro). Other livelihood sources include forest products and off-farm work.
Irrigated	48	Large-scale irrigation schemes associated with large rivers across Africa, e.g. Nile, Volta. Often located in semi-arid and arid areas but with medium-high access to services. Includes the associated surrounding rainfed lands. Diversified cropping includes irrigated rice, cotton, wheat, faba, vegetables and berseem augmented by cattle, fish and poultry.
Arid pastoral and oasis	8	Extensive pastoralism and scattered oasis farming associated with sparsely settled arid zones across Africa, generally with very poor access to services. Livelihoods include date palms, cattle, small ruminants and off-farm work, irrigated crops and vegetables.
Perennial mixed	12	Semi-commercial and commercial farming with good access to services, dominated by perennials such as vines, fruit and eucalypts, found in Mediterranean (subhumid) climates in the coastal areas and hinterlands in Southern and North Africa. Other livelihoods include sugarcane, maize, legumes, cattle and small ruminants.
Island	4	Mixed cropping, horticulture, sugarcane and fishing in the principal islands associated with Africa. Other livelihoods include livestock. Often there is medium access to domestic and tourist resort markets, but limited exports.
Urban and peri-urban	na	Located within cities, or on their fringes with high population density and medium-high access to services and markets, often informal. Livelihoods include fruit, vegetables, dairy, cattle, goats, poultry and off-farm work.

Source: Based on existing data and author expert judgements for the year 2015. Off-farm work can be found in all systems, but is noted where it is a main livelihood.

crop mixed farming system, with dramatically different needs related to infrastructure, credit, market development and research.

Farm women and men are the key decisionmakers in the management of natural resources, farm production, family consumption and farm investment. The decisions are framed by formal and informal institutions which are influenced by community values, public policies, markets, resource access regimes and the knowledge, skills and experience of the household, with the broad goal of improved individual and community welfare (Figure 1.2). Climate and economic risks are major considerations in operational and tactical farm and household management decisions. Farm households have a leading role in the management of natural resources – this is sometimes overlooked. Also, with increasing opportunities for women in agriculture, women are playing a wider role in farm management decisions. Other family members, including the elderly and the youth, also may influence strategic management and investment decisions.

There are strong linkages between increased crop or livestock productivity, improved farm household food security and reduced rural poverty. In good seasons or on medium-large farms, food crop surpluses are sold. Smallholders may sell at harvest and then purchase later in the year when their household stocks have been consumed. Although there are exceptions, sales of farm or household produce increase purchasing power, and they generally improve household food and nutrition security and reduce poverty. Increased

food crop productivity often creates opportunities for diversification to higher value cash crop, tree or livestock income for households. Additional off-farm wage income also increases food purchase entitlements, often for the most vulnerable households, and offers flexibility for increasing purchases of fertilizer and other agricultural inputs. Population density and the level of infrastructural development influence the rate of spread of these outcomes. For these reasons, the mix of food crops, cash crops, livestock and trees, and their inter-linkages, is often an important determinant of food security outcomes. Gender roles in household decisionmaking and the management of income also shape the poverty, food and nutrition security outcomes. Farm size and wealth also count: normally smallholders spend a high proportion of additional income on local goods and services, whereas larger farmers tend to spend more outside the region.

Figure 1.2 Farm household decisionmaking connecting resource management, production, consumption, investment and welfare.

The households in a farming system pursue recognizable strategies to secure household food and nutrition security, increase income, improve livelihoods and satisfy other household goals. For example, pastoralists with limited market access might seek to grow herd size while smallholder vegetable producers might endeavour to intensify production of profitable vegetables sought by the market. The strategies naturally depend upon the prevailing livelihood patterns and opportunities, as well as the pattern of smaller and larger farmers, female- and male-headed households and differing degrees of dependence on off-farm income, cash crops and livestock in the farming system. One typology in the maize mixed farming system in Malawi differentiated households, which were ‘hanging in’, ‘stepping up’ or ‘stepping out’ (Dorward 2009). Such pathway-oriented typologies represent one way to identify evolving patterns of social organization, and they are useful to understand the needs for technology and institutional innovations, and to guide research and policy decisions. Clearly, the development needs and constraints of individual households within one farming system, such as the maize mixed farming system, are more similar to one another than to the households in another farming system.

In broad terms, small farm households have five main strategies to improve livelihoods and household food security or escape poverty, as follows:

- intensification of existing production and processing patterns
- diversification of production and processing patterns
- expanded farm, enterprise or herd size
- increased off-farm income, both agricultural and non-agricultural
- exit of the whole family from farming in the particular farming system.

These strategic options are not mutually exclusive: any particular household will often pursue a mixed set of strategies.

Intensification is defined as increased physical or financial returns from existing patterns of production, representing greater productivity of agricultural outputs including food and cash crops, livestock, trees and other beneficial activities. Although intensification is frequently associated with increased productivity as a result of greater use of purchased inputs, intensification may also arise from improved knowledge that leads to better use of existing household resources, including varieties and breeds, and labour and farm management skills, for example improved irrigation practices or better pest control. In Africa today, access to productive technologies, input and output markets often drives intensification. Readers are cautioned on the limits to rainfed crop-based intensification, partly because small farm sizes limit potential gains in household income. The concept of ‘intensification’ adopted in this book relates to increased productivity of existing farm activities, in contrast to on-farm diversification (see the following paragraph) and broader, landscape level, agricultural intensification which includes the introduction of new crops or livestock.

On-farm diversification is defined as an adjustment to the farm enterprise pattern in order to increase farm income or livelihoods. Often, there is a corresponding reduction in risk or income variability. Diversification exploits new market opportunities or existing market niches. Diversification may take the form of completely new enterprises, or may simply involve the expansion of existing, high value, enterprises. The addition or expansion of enterprises refers not only to production but also to on-farm processing

and other farm-based, income-generating activities. Farm women and men's knowledge, adequate technologies (even if adaptation might be required) and access to markets often drive diversification. Diversification, as used in this analysis, should not be confused with improved livelihoods from off-farm sources or additional off-farm income, as found in some rural development literature.

Some households increase income or escape poverty by expanding the farm business size – in this context size refers to managed rather than to owned resources – especially where population density is low, land rights permit and finance is available. Beneficiaries of land reform are an obvious example of this source of poverty reduction. Increased farm size may also arise through incursion into previously non-agricultural areas such as forest – often termed expansion of the agricultural frontier. Two other examples are increased herd size where grazing land is available, and settlers on new irrigation schemes. Although this option is not available within many systems, it is of relevance particularly in parts of Latin America and SSA. Increasingly, however, such 'new' lands are marginal for agricultural purposes, and they may not offer sustainable pathways to poverty reduction.

Off-farm income represents an increasingly important source of livelihood for many poor farmers. Seasonal migration has been one traditional household strategy for escaping poverty. Remittances are often invested in land or livestock purchases. In locations where there is a vigorous off-farm economy, some individuals from poor households augment the family income with part-time or full-time off-farm employment.

Where opportunities for improved livelihoods are perceived, a proportion of farm households will abandon their land and/or herds altogether, and relocate the whole family into other farming systems, or into other rural or urban locations with economically attractive off-farm activities. This means of escaping agricultural poverty is referred to in the following chapters as an exit from agriculture.

These poverty escape strategies refer to extremely poor households which form a significant proportion (sometimes more than half) of the farming population in all systems. The balance of farm households is somewhat better off with greater than US\$1.90 consumption per day; a small proportion could be termed 'well off'. The same five strategies apply to the 'non-extremely poor' farm households in relation to the enhancement of livelihoods and incomes. Typically, the strategy mix of poor households differs from that of better-off households, whether smallholder or medium commercial farms.

The above five household strategies for reducing hunger and poverty, and enhancing livelihoods and incomes, will be referred to frequently in the following chapters and their relative importance assessed, based on the judgement of experts who are knowledgeable about each particular system (see also Chapter 2).

Drivers and trends shaping African farmers' opportunities

Overall changes in farming systems since 2000

Since the origins of agriculture, the geography of crops, extent of livestock and the patterns of land use have continued to change. The degree of change in African farming systems over the period 2000–2015 is substantial. The agricultural population density has increased (even allowing for rural–urban migration) leading to a reduction in farm size, intensification of production and induced innovation in production practices. Meanwhile, agricultural market access has improved markedly, which has stimulated major changes in crop combination, herd composition and marketing of surpluses, but

notably not the widespread adoption of fertilizer. The farming systems with traditional export crops such as cocoa or coffee have maintained well-organized market systems. Another effect of improved service endowment has been diversification towards marketable crops and livestock. Such effects are most pronounced in the highland perennial farming system but are also evident in most farming systems including the maize mixed and cereal-root crop mixed farming systems. There has been an expansion of cultivated area in the majority of farming systems, notably the forest-based, cereal-root crop, maize mixed and agropastoral farming systems – reducing (but not off-setting) the pressure from increased population density. Notably, the land frontier has closed or is closing in many farming systems, including the four named earlier and the highland perennial and highland mixed farming systems.

Consequently, this analysis reflected the evolution of farming systems over the period 2000–2015. For example, where maize has been widely adopted in Central African areas that were originally cereal-root crop mixed systems, the areas were reclassified to the maize mixed farming system. The combination of changes in rural consumer preferences and the development of drought tolerant maize has also increased the proportion of maize, alongside sorghum and millet, in the agropastoral farming system, but not sufficiently to reclassify the farming system. The dualistic system characterized by mixed large-scale commercial and small-scale farming in Southern Africa was reassigned to other systems, notably the maize mixed and agropastoral systems. Market development has created more opportunities for smallholders in East Africa, in particular horticulture and dairy, and consequently the commercial smallholder highland perennial system has been enlarged. The key changes in the extent of farming systems over the period 2000–2015 are:

- creation of a newly delineated perennial mixed system in Southern Africa
- distribution of the large commercial and smallholder farming system entirely to other systems, notably perennial mixed, maize mixed and agropastoral systems
- adjustment of boundaries of many systems reflecting, primarily, increased population density, improved infrastructure and access to agricultural services, and improved technology and institutions
- substantial reduction in the extent of the cereal-root crop mixed farming system.

Quite apart from the major spatial changes, farming systems are changing incrementally. Some changes are visible, such as deforestation to expand cultivated land, but others relate to resource use, resource quality (e.g. fertility decline) or economic and social relationships (e.g. returns to labour, changing social capital). These build pressure over time which can generate step changes in enterprise combination or technology adoption. The trends and resulting pressure points can be identified by careful analysis and then future changes predicted. In the medium term, a set of universal drivers frames the evolution of each farming system along relatively predictable pathways. The seven drivers are:

- population, hunger and poverty
- natural resources and climate
- energy
- human capital, knowledge sharing and gender
- science and technology
- markets and trade
- policies and institutions.

Table 1.5 Principal drivers and trends in farming system development

<i>Drivers (trends)</i>	<i>Example metrics</i>	<i>Example influences on farm household decisions</i>	<i>Example influences on structure and function of farming system</i>
Population, food security and poverty (increased pressure)	Population density, migration, urbanization, diet, under-nutrition, poverty	Labour availability and productivity, farm practice adoption decisions, schooling, risk avoidance	Labour-saving technologies, reduced herding/expanded stall feeding, low investment
Natural resources and climate (reduced availability and quality)	Farm size, herd size, irrigation, land tenure, land degradation	Scarcity of land and nutrients creates incentives for irrigation and soil management, increased climate risk	Reduced farm and herd size, reduced land/labour ratios, shift from extensive to intensive practices, stronger integration of crops, trees and livestock
Energy availability and use (increased availability, volatile prices)	Energy availability and use, firewood use, electrification	Timeliness of operations, replacement of labour	Earlier planting, better weeding, post-harvest processing, appropriate mechanization, small-scale irrigation
Human capital, knowledge sharing and gender (improved education, information and benefit sharing)	Education and skill level, mobile phone ownership, extension/farmer ratio	Improved farm decisions and management, improved benefit sharing, adoption of new practices or enterprises, greater involvement of women in decisions	Diversification, increased eco-efficiency (water and nutrient use efficiency), greater market orientation, improved gender equity, better farm-household management and increased total factor productivity
Science and technology (increased technology choices)	Productivity, technology adoption	Adoption of better practices and enterprises	Increased eco-efficiency, expanded production, improved quality of produce
Markets and trade (expanding market access and reduced marketing costs)	Input use, market surplus, supply chain length, food system structure, competition, agribusiness investment	Increased productivity, diversification, value-adding	Stronger market orientation and commercialization, reduced capital and transaction costs, greater intensification and diversification
Institutions and policies (strengthening institutions)	Expenditure on agriculture (incl. research, input subsidies, infrastructure), new regulations	Adoption of institutional innovations (markets, finance, risk sharing, conditional prepayment rate management)	Improved resource management, farmer group and cooperative coordination for marketing and resource management

The drivers correspond in general terms with the various drivers identified by other authors. For example, Reardon and Timmer (2014) identify five ‘transformations’ of the Asian agrifood economy (urbanization, diet changes, food system transformation, rural factor markets and capital-led farm technology intensification); these apply in part in Africa. Jayne (2016) and other authors describe other similar sets of mega-drivers.

In practice the above seven drivers interact, and the reader might anticipate a fundamental nexus between population density, access to natural resources and access to services including markets. It is important to note that trends (increasing, decreasing, steady) associated with each driver can rarely be assumed to be constant or linear. Whether there are ‘necessary’ and ‘sufficient’ conditions for change in each set of drivers plays out differently for different situations and for different farm sizes.

The above seven drivers influence farm household production and consumption decisions and farming system structure and function. Table 1.5 introduces the seven principal drivers which shape the development of farming systems structure and function in Africa; these are discussed in greater depth in the following subsections.

Population, hunger and poverty

People lie at the heart of sustainable development and farming systems options, and rapid population growth is dramatically shaping the limits and opportunities of farming pathways in all parts of the continent. Since 2000 the African region has had the fastest growing population in the world, and this is projected to continue for the coming decades. The total regional population was 1.2 billion in 2015 of whom 585 million (about half) were classified as agricultural. Regional population growth rate has been about 2.6–2.7 per cent p.a. since 1990, despite the effect of HIV/AIDS, but there is considerable variation across countries, for example the Ethiopian population growth rate is above 3.0 per cent. In the African context, such high growth rates boost the food economy and increase the dependency ratio of young and old on the workforce. While fertility rates have begun to drop in urban areas, the rural household’s traditional path to social security had been to have many children. However, there are indications of a growing emphasis in rural areas towards small families and well-educated children who can compete in the job market and earn off-farm income for the family.

The trends shown in Table 1.6 for SSA are indicative of the wider African situation. The SSA rural and agricultural populations are growing in absolute size although declining as a proportion of the total, partly because of rural-urban migration. Between 2010 and 2050 the rural population is projected to increase by 56 per cent, and the agricultural population by a slightly lower proportion. The SSA urban population is expected to surpass the rural population in about 2035. Such rapid urbanization stimulates urban and peri-urban farming, and influences other farming systems through opportunities for meeting growing and changing urban middle class demand for food. These demographic changes are expected to lead to a slower rate of decline in the land/agricultural population ratio and farm size – although the current person-land ratio is relatively low compared with that of Asia.

Such massive demographic changes raise four critical and interrelated policy issues. First, although the proportion of farmers in the total population is projected to decline from 56 to 33 per cent by 2050, the number of farmers will increase by half. Second, accordingly, in some farming systems with substantial forest or well-watered grazing lands, conversion of forest or grazing land to cropping is expected (as has happened since 2000

Table 1.6 Trends in population and food security in sub-Saharan Africa compared with the world

	1970	2000	2010	2050
SSA total population (million),	285	642	823	1892
(SSA total pop as % of world)	(8)	(10)	(12)	(20)
SSA urbanization (%),	20	32	36	56
(Global urbanization %)	(37)	(47)	(52)	(67)
SSA agricultural population (million),	206	368	428	617
(SSA ag pop as % of world)	(11)	(14)	(16)	(29)
SSA agric pop as % of total SSA pop,	72	57	52	33
(Global agric pop as % of total global pop)	(83)	(79)	(38)	(23)
SSA farm households (approx million)	38	67	78	112
Household food security (kcal/person/day),	–	2188	2495	2580
(reference year of estimate)		(mid-1990s)		(est 2030)
Undernourishment (% of population),	–	33	24	15
(year of estimate)		(1991)	(2014)	(2030)

Sources: FAO (2015), IFPRI (2015).

Notes: SSA agricultural and farm household populations in 1970 and 2050 were estimated by the authors.

in the forest-based and agropastoral farming systems). In other more densely populated farming systems (such as the highland perennial or highland mixed), average farm size is expected to decline (average farm size has already declined in many farming systems). Third, in either case, increased farm productivity is required, because, in the absence of a major expansion in food imports, each farm household will have to feed three households (themselves and two urban households – the equivalent global ratio will be four to one). Fourth, without adequate mechanization, system intensification and diversification could be held back by labour shortages. A further critical policy concern is whether sufficient viable employment opportunities in secondary and tertiary sectors can be generated to absorb rural populations leaving agriculture, to avoid hotbeds of unemployment and poverty in expanding peri-urban slums which already account for about 60 per cent of the urban population in Africa.

Household food security is a critical determinant of farm family decisions about production and consumption. Food security has energy and nutritional dimensions, and can be analysed from the demand side, supply side and the linking market systems (Qureshi et al. 2015). In SSA nearly half of the rural households are not food secure, with great variation in the distribution of undernourishment across farming systems and between years. In practice, most poor households lack food security, but some well-off households are also malnourished because of nutritionally unbalanced diets. However, the situation is improving, as shown in Table 1.6.

Off-farm income through wages or micro-business is an important source of cash for purchasing food, noting that a high proportion of African smallholders are net purchasers of food. In this context household or per capita income, or average GDP per capita, is an important indicator of purchasing power. Improved cash incomes may alleviate the risk of food entitlement failure, often described in terms of food production, market and consumption risk.

In the mid-1990s the average dietary energy consumption was 2188 kcal/person/day (compared with 2626 in developing countries as a whole). By 2010, dietary energy intake had increased to about 2495 kcal/person/day. Up to 2030, the average energy intake is projected to increase to 2580 kcal/person/day. In spite of the increased calorie supply, it is estimated that in 2030 around 15 per cent of the population (about 165 million people) will still be undernourished – an increase in the absolute number – unless deliberate measures are taken to ensure better access to food. Overall, it is clear that energy and nutrient deficiencies have constrained farmer activities and productivity, and they have slowed development, with long-term consequences for farming systems development.

Natural resources and climate

In many areas, as rural populations have grown, the availability of land for agricultural expansion has become limited. While African farmers have traditionally fallowed depleted cropland to restore soil fertility, many are now forced to crop some of their fields continuously. Fallowing has reduced or has been phased out in some systems. There is increased competition and more frequent conflicts between farmers and livestock herders regarding access to land used for community grazing in the past, thus reducing opportunities for crop-livestock synergies including manure production. The intensity of farming has increased often with inadequate investment in land management to restore fertility and limit soil erosion and other land degradation. Thus, maintenance of crop yields in the face of soil impoverishment has become a primary concern for many smallholder farmers across a range of farming systems.

Approximately two-thirds of agricultural land in SSA is estimated to be subject to degradation. These trends are worrisome, considering the imperative to increase agricultural yields to feed the rapidly growing population. Land degradation and the concurrent depletion of soil fertility which affects agricultural productivity has become a central development issue for policymakers, accentuated by climate change. As noted earlier, Africa is relatively well endowed with natural resources. However, soil resources are heterogeneous, with both some areas of deep fertile soils but also large areas of infertile and highly erodible soils (Inter Academy Council 2004).

One of the best overall indicators of natural resource health is net primary productivity, which varies according to regions in Africa. The decline in the annual biomass productivity of the land is particularly evident in the maize mixed farming systems in Zambia, Angola, DRC, Mozambique and Tanzania. There has also been marked degradation in the forest-based systems in the countries of the Congo Basin. Much of this loss of biomass productivity is due to forest clearing for agriculture, followed by lower productivity land use mosaic when forest is not allowed to sufficiently regrow. In contrast, biomass productivity in some parts of Sahelian and Sudanian West Africa has increased since the late 1990s, particularly in the agropastoral and cereal-root and tuber crops farming systems.

In relation to the 660 million ha of forest (about one-quarter of total land area), current annual deforestation is 0.16 per cent. The decline in closed-canopy forest area is expected to continue. However, as forest area declines and agricultural land is degraded, farmers have begun to regenerate or plant trees on crop lands. This trend, apparent in the agropastoral systems of the Sahel, is associated with the improved nutritional status of households. Wetlands and national parks are also often under pressure, despite national land use regulations or international conventions.

Over recent decades, rainfall patterns have changed across the globe, potentially affecting Africa more than other regions. In Africa, the most affected farming systems are likely to be those in the arid, semi-arid and dry subhumid areas, for instance the agropastoral and pastoral farming systems. The increasing frequency and severity of droughts are likely to cause more crop failures, high and rising cereal prices, low and falling livestock prices, decapitalization, distress sales of animals, and hunger. Vulnerable farm households are likely to buffer crop and livestock livelihoods with off-farm income, for instance seasonal migration, and wood and charcoal sales are common non-farm income sources. The above pressures could exacerbate land degradation and deforestation, accelerate the onset of desertification and drive people temporarily or permanently into more favoured farming systems, for instance the cereal-root crop mixed and maize mixed farming systems, and into urban areas. As a result, rural conflicts over resources will become more common, including between sedentary farmers and pastoralists.

Food and agricultural use of land has expanded steadily across Africa. Of the total land area, about 38 per cent was agricultural land, and approximately 9 per cent of total land was used for annual or permanent crops by 2015 (Table 1.7). The cultivated area increased from 170 million ha in 1961–1963 (including annually cultivated land and permanent crops) to 272 million ha by 2015 – mostly through the conversion of forest and grasslands and the shortening of fallows. Further expansion is possible. It is estimated that the Africa region has up to one-half of global agricultural land available for the expansion of crop land. The availability of suitable arable land in Africa for food and bioenergy crop production attracted much foreign investment and led to intense policy debates, especially since the 2008 food price spike. However, the momentum underlying the bioenergy crop production objective was undercut by recent changes in the European Union's biofuels policies. As the food price spike passed, the priority for overseas food production abated. Domestic investment is now balancing foreign investment in large-scale farming ventures and is also being scaled up in medium-sized family farming.

Under existing climatic conditions, the region has large areas with high potential for rainfed cropping and grazing, and opportunities for expansion of surface water irrigation backed up by extensive (newly discovered) groundwater reserves. Only 2 per cent of the available water resources were utilized for irrigation (15.8 million ha equipped in 2015), compared with 20 per cent in developing countries overall. Projections suggest continued expansion of irrigated areas until 2030.

Table 1.7 Trends in land use in Africa

<i>Land use (million ha)</i>	<i>1970</i>	<i>2000</i>	<i>2015</i>
Agricultural land area	1057	1123	1133
Forest land area	–	670	624
Crop land, including permanent crops	186	230	272
Permanent crop land	17	28	34
Permanent meadows & pasture	870	893	861
Land area equipped for irrigation	8.4	13.2	15.8

Source: FAOSTAT (2015).

Notes: data are indicative, whole of Africa data.

Table 1.8 Trends in livestock and poultry populations in sub-Saharan Africa

<i>Animal type</i>	<i>1970</i>	<i>2000–</i>	<i>Growth rate 1970–2000 (% p.a.)</i>	<i>2010</i>	<i>Growth rate 2000–2010 (% p.a.)</i>	<i>2050 (estimate)</i>
<i>Population (million head)</i>						
Cattle	129	181	1.7	234	2.6	272
Sheep	114	150	1.7	199	2.3	330
Goats	92	184	3.9	269	3.2	446
Poultry	321	766	4.9	1162	3.0	1704
<i>Stocking rates on agricultural land (head/ha)</i>						
SSA cattle	0.14	0.20	–	0.24	–	0.21
(global ratio)	(0.26)	(0.30)		(0.33)		(0.35)
SSA sheep and goats	0.8	1.8	–	2.3	–	2.8
(global ratio)	(2.0)	(4.1)		(5.4)		(7.0)
<i>Farm household ownership (head/household)</i>						
Cattle	3.4	2.7	–	3.0	–	–
Sheep	3.0	2.3	–	2.6	–	–
Goats	2.5	2.8	–	3.5	–	–
Poultry	8.0	8.8	–	10.5	–	–

Source: FAOSTAT (2015).

Notes: The livestock populations and stocking rates are projections to 2050 derived using growth rates generated from the IMPACT model version 3.0 (Enahoro, Tarawali pers. comm.; Robinson et al. 2014).

Livestock are first and foremost an asset for many smallholders. Animal populations in SSA are expanding steadily, as shown in Table 1.8. Poultry and goat numbers have expanded rapidly and nearly trebled over the four decades from 1970 to 2010; cattle, sheep and camels have nearly doubled in numbers during this period. Fishing activities are also increasing in response to local demand from growing populations as well as from cities and for exports, and this offers a form of relatively liquid household savings.

Both agricultural and livestock populations have increased substantially over the three decades to 2010. However, the number of cattle and sheep per farm household have decreased somewhat, in contrast to an increased household holding of goats and poultry. There is, of course, greatly increased pressure on grazing lands (Table 1.8) and crop residues as a result. Continued increase in livestock and poultry is expected, driven by market opportunities and relative prices. In fact the stocking rates are significantly lower in Africa than other parts of the world, which suggests scope to further increase livestock numbers through the use of technologies and institutions for crop-livestock integration.

Energy

In Africa, only approximately 2 per cent of energy consumption is devoted to agricultural and forest production, and this has been relatively steady over the past several decades. There

is a marked variation in energy use between different parts of Africa, with Western Africa reporting less than half the agricultural and forestry energy intensity of Southern Africa.

Two major uses of energy in production are tillage (depending on whether manual, animal draught or mechanized) and water pumping for small-scale irrigation. In marketing, transportation is the dominant use of energy for input and produce chains. The intensification of food production will require greater use of energy for traction, inputs and processing of outputs, although crop production using conservation agriculture¹ practices is energy saving at the field level. Energy and food markets are now interlinked and price movements are correlated. Energy efficiency in food production, processing and marketing will be critically important in future decades.

Human capital, knowledge sharing and gender

Knowledge can be a powerful driver of farming systems development in many ways, and so information, human capital and inclusive approaches merit the close attention of policymakers. A key trend is the ‘feminization’ of farming as young males seek seasonal and longer-term employment in cities and other countries, leaving women as the *de facto* farm managers. Improved farm household decisionmaking, increasingly by women, requires strengthened capacity through education and farmer training, supplemented by the dissemination and sharing of technological, market, policy and institutional information.

Communication technologies such as radio and mobile phones have accelerated access to information through formal and informal networking, and strengthened social capital and farmer-to-farmer sharing. Of the new communication technologies, mobile phones have had the most far-reaching effects. Two aspects of mobile phones are widely recognized: their rapid adoption and their potential use for agricultural information dissemination. There has been an explosion of mobile phone ownership since the mid-2000s in many African countries. Interestingly, mobile money exchange is expanding at a similar rate to mobile phones in Kenya, albeit with a lag of about four years. Information communication technologies (ICTs) may well revolutionize agricultural technical and market information sharing and offer the potential for fully interactive decision support services – along similar lines to India.

Science and technology

Science and technology, supported by appropriate policies and institutions, have an important role in resource management and productivity growth in crops and livestock in future decades, which is essential to reduce African poverty and food insecurity. Important innovations which have emerged in recent years include improved varieties and breeds, conservation agriculture, better pest control and improved nutrient management – and also a range of institutional innovations which enhance information availability (e.g. ICTs), market access and reduce risk (e.g. index insurance). As a generalization, the past and existing innovations streams seem to have benefited higher potential farming systems (e.g. cereal-root crop mixed system) more than low potential farming systems (e.g. agropastoral and pastoral systems). The existing portfolio of innovations also appear to favour increased productivity over risk management and adaptation to climatic variability. Furthermore, some technologies are not well suited for existing farming systems which, together with weak scaling institutions, have led to low adoption rates.

Increased investment in agricultural research (which shows consistently high economic high returns) is of fundamental importance for the continued supply of innovations to

underpin future food and nutrition security. It is expected that the contribution of the private sector to research will grow in the coming years. The concentration of research effort in a small number of countries creates opportunities for the ‘spillover’ of innovations between countries with the same broad farming systems.

The aggregate capacity of SSA agricultural R&D institutions is growing in terms of the absolute number of researchers and real public budget. However, when compared with the agricultural sector size, the number of researchers per million economically active agricultural workers has risen only slightly from 5.7 in the early 1980s to almost 7.0 in 2011; the public agricultural research intensity (the expenditure in relation to the Agricultural GDP) has declined over the same period from 0.6 per cent to about 0.5 per cent (compared with the recommendation of 1 per cent research intensity by the New Partnership for African Development (NEPAD)).

The Forum for Agricultural Research in Africa (FARA) has launched its Science Agenda, which provides a forward-looking framework for agricultural innovation. It recognizes the diversity of African agriculture and the different technology and investment needs of various farming systems. The incorporation of the farming systems framework into the Agenda offers a template for the management of spillovers between countries sharing the same or similar farming systems.

Although many metrics of research effectiveness exist, one of the most popular is the relative increase in food crop yields or animal productivity. Another indicator of technology uptake and effectiveness is the rate of closure of yield gaps. Often, technologies are embedded in inputs, so greater use of improved seed or fertilizer is also a useful proximate indicator.

The gaps between farm yields and potential yields are very large for most African crops and livestock production (larger than most other regions of the world). Cereals, fruit, maize and rice have shown modest to strong yield growth since 1970 – this has continued for cereals until 2015. However, the areas harvested of most food crops have expanded alongside the increases in yields. For example, while the yield of maize has increased 1.2 per cent per annum since the late 1980s, the maize area has expanded by 1.5 per cent per annum.

Total crop production is forecast to increase by about 70 per cent over the period from 2010 to 2050. Major increases are expected to come from expanded production on heavy lowland soils scattered across the continent in several different farming systems, in the humid and moist subhumid tropics, and on irrigated land in the maize mixed and several other farming systems. Despite the growth in demand for small-scale irrigation, most food production in Africa will continue to come from rainfed farming.

Livestock and poultry productivity compares favourably with global averages (using the partial productivity metric of kg meat per head; see Table 1.9) except in the case of cattle. Compared with Asia and Europe, Africa has progressed poorly with an overall beef (and buffalo) carcass increase of around 12 per cent over the period 1961–2012, compared with around 40 and 76 per cent in Asia and Europe respectively. As of 2012, average carcass weight in Africa is only 65 per cent that of Europe. However, cattle and sheep recorded an overall increase in productivity between 1970 and 2010, which is expected to continue in the coming decades.

Milk and meat production is expected to triple between 2010 and 2050 in response to strong income-induced demand. Because of different demand patterns, milk production is expected to expand most rapidly in East Africa and poultry production in West and Southern Africa. The increased demand for feed grains will have knock-on effects on crop production.

Although food crop yields have begun to rise recently, African yields lag behind Asia and developed countries for a variety of abiotic, biotic and institutional reasons. Land

Table 1.9 Trends in livestock and poultry productivity in sub-Saharan Africa and globally

<i>Animal type</i>	<i>1970</i>	<i>2000</i>	<i>2010</i>
Cattle meat, kg/head	153 (182)	155 (206)	170 (212)
Sheep meat, kg/head	13.0 (15.1)	12.5 (15.8)	14.9 (15.7)
Goats meat, kg/head	11.7 (10.9)	12.6 (11.8)	12.6 (12.1)
Poultry meat, kg/head	1.0 (1.3)	1.2 (1.6)	1.2 (1.6)

Source: FAOSTAT (2015).

Note: Estimates are indicative, based on unweighted averages of the four regions of SSA. Global productivity data are shown in parentheses.

degradation and climatic variability are the two main abiotic constraints. Inorganic fertilizer consumption is very low in SSA despite the declining soil fertility noted earlier. From 2002 to 2010, inorganic fertilizer usage was low and scarcely increased (from 11.6 to 11.7 kg N/ha) compared with an increase in global nitrogen nutrient application from 57 to 69 kg N/ha (FAO 2015). The use of compost or other soil amendments is important but does not compensate for these very low levels of fertilizer use.

The adoption of improved varieties of food crops has increased since the late 2000s, especially in Eastern and Southern Africa (one example is drought-tolerant maize). It is expected that the share of modern varieties will grow, inorganic fertilizer application will increase and mechanization will substitute for labour, especially that of women. Similarly, livestock industries will intensify with improved breeds, especially in the dairy sector, and increased use of planted forages and purchased feed. The current trend of tree planting and farmer-managed natural regeneration of trees on farmlands is expected to accelerate.

Biotic constraints also contribute strongly to large productivity gaps for both crops and livestock. Cassava and maize suffer from widespread and severe virus and insect attacks (for example, cassava mosaic virus and mealy bug, and maize lethal necrosis and stem borer). Tsetse infestation is a major factor influencing the distribution of livestock between different farming systems. Tsetse tends to be concentrated in the moist subhumid and humid lowlands, and in drier areas near game reserves, so cattle numbers per household tend to be higher in the dry farming systems than in the moist systems.

The ratios of agricultural workers to farm land influence the trends in crop, livestock and tree productivity. As outlined earlier, with relatively low population pressure on land, per capita food production in Africa has increased steadily, principally through extensification, that is, expansion of cropped area (World Bank 2008), supplemented by some yield increase. In contrast, increases in Asian cereal production arose principally from yield growth. Sometimes this contrast is explained by the overly simplistic notion that the Green Revolution has not yet reached Africa. However, the reality reflects the particular combinations of available land for expansion, population pressure, poverty, farming techniques, investment in R&D, patterns of adoption of science and technology, and input markets and trade. The increasing population in Africa, and the limits to land expansion, will place pressure on households to increase yield and intensify and/or diversify farming. It is noteworthy that trends in other countries pose opportunities and

risks for Africa. For example, the cereal area has contracted in Europe as oilseeds and other high value crops were substituted for cereals, while cereal yields have increased.

Markets and trade

Agribusiness, markets and trade are all vital for agricultural development, and they require policy attention. Farming system intensification and diversification require an increasing volume of services, especially markets and suitably priced and available inputs. In fact, access to services, including markets, fundamentally influences the directions of farming systems development – sometimes this is even more important than the natural resources–population nexus. At a continental scale, the level of services and integration of markets will shape how effectively Africa responds to the challenges of the surging aggregate purchasing power of domestic consumers accompanied by changing consumer preferences.

Until recently agriculture accounted for about half of East African exports, whereas in West and Central Africa agriculture's share of total exports declined from over 70 per cent in 1961 to less than 10 per cent in 2015, partly as a consequence of the expansion of petroleum and mineral exports. Africa's principal agricultural exports are cocoa, coffee and cotton, although sugar, wine and fruits are significant exports in Southern Africa.

The proportion of agricultural products within total imports to the region has been rising. Cereal imports rose ten-fold over the period 1970 to 2010, from 6.5 Mt to 66.4 Mt, largely comprising rice and wheat imports (in contrast to cereal exports of 3–4 million Mt). If these trends continue, in 2030 the region would need to import an estimated one-sixth of its total cereal requirements. Generally, food aid has represented less than half of cereal imports; nonetheless, per capita food aid flows are larger than those to Asia and Latin America. Significantly, meat imports have increased nine-fold from 1970 to 2010, to 1.8 Mt (compared with 0.2 Mt exports).

Cereal and meat imports have surged, while exports have stagnated – despite attractive international prices and apparent, or at least potential, African competitive advantage in their production. Fortunately, intra-Africa regional trade now is growing more rapidly than international trade.

At the farming system and farm household levels, access to markets is mediated by local institutions, culture and traditions, which also influence the nature of current farming systems. Changing trade patterns can also reconfigure farming systems, for example changing trade led to the collapse of the sisal plantations in Tanzania and, later, the growth of smallholder dairy, floriculture, pigeon pea and export vegetables. However, the influence of market access is generally more nuanced, leading to practice change or an increased rate of diversification.

Access to markets can be measured in many ways, and the most common, but admittedly crude, metric is the shortest travel time to market (typically a mix of foot, animal and vehicular transport). Not surprisingly, yield gaps and farm performance gaps increase with greater distance to the national capital (which may determine access to a much broader bundle of services especially outside agriculture, including health and educational services). Naturally, transport infrastructure underpins market access. In the year 2000, SSA had only 8 km of rural roads per 100 km² of land, compared with 22 km worldwide and 25 km in Asia (FAO 2015), but global projections are that more than two-thirds of new roads planned for construction by 2040 will be located in Africa, indicating the potential for improved access to markets (but also a corresponding risk for biodiversity).

Agribusiness' principal roles are in market chains, storage, processing and distribution. Investment in input chains and agricultural service provision is essential for increased productivity and production of marketable surpluses, thus affecting intensification, diversification and growth of farm businesses. There are often high returns to investment in weak input markets such as finance, knowledge, seed, fertilizer and machinery. Once there are functioning input markets, investment in produce market chains becomes feasible. Not only are 'business-friendly' policies required but also mechanisms to mitigate business risk stemming from climate variability in rainfed farming. In most contexts, African under-investment is greater in micro and small rural enterprises than in large corporations; it is sometimes argued that micro and small rural enterprises could underpin the next agricultural development revolution.

Policies and institutions

The perspectives shaping African agricultural policies have evolved since the food self-sufficiency goal expressed in state-led modernization in the 1960s. During the 1970s the intensification perspective of the Asian Green Revolution resonated with many African leaders. There was considerable interest in integrated rural development programs (IRDPs) which linked agricultural development to infrastructure, education and health services. During the 1970s and 1980s public agencies for R&D were strengthened. Multidisciplinary farming systems research with farmer participation was promoted and explored the 'systems-fit' and social aspects of technologies and market linkages in the complex smallholder systems. However, during the structural adjustment era of the 1980s and 1990s, much of the investment in public research and extension capacity was eroded, along with agricultural statistics and other agricultural services. The hopes that the private sector would fill the gap were not realized to the expected level (Mburathi pers. comm.). Today, it is clear that liberalization reform targeting economic growth needs to be complemented by food and nutrition security measures through agriculture as the core focus for development.

The Africa Union (AU) has encouraged improved governance at all levels. There are now many instances of successful regional, national and local institutions which stimulate sound resource management and productivity growth (UNDP 2015).

Regional agricultural development policy in Africa is principally shaped by the strategic framework of CAADP, which is aligned with the Sustainable Development Goals. In 2003, in Maputo, Mozambique, the African Heads of State and Government endorsed the CAADP as a framework to create an ambitious institutional and policy transformation in the agriculture sector. The CAADP development agenda is basically growth oriented. It aims to increase agricultural growth rates to 6 per cent per year, supported by at least 10 per cent of national budgets devoted to agriculture. CAADP focuses on four key pillars: expanding sustainable land management and reliable water control systems; improving rural infrastructure and trade-related capacities for market access; increasing food supply, reducing hunger and improving responses to food emergency crises; and improving agriculture research, technology dissemination and adoption.

Cross-cutting issues include, but are not limited to, capacity strengthening for agribusiness; academic and professional training; and improving access to information for agricultural strategy formulation. CAADP has substantially raised the profile of agriculture in national domestic politics, contributed to the development of incentive-oriented agricultural policies, facilitated the alignment of development partners to country priorities,

and has improved regional coordination. CAADP has been moving forward on both regional- and country-level processes.

Since the 2003 Maputo Declaration, African leaders have adopted various additional decisions and declarations on agriculture and food security, within the overall framework of CAADP. These decisions include, notably, the 2004 Sirte Declaration on the Challenges of Implementing Integrated and Sustainable Development in Agriculture and Water in Africa; the 2006 Resolution of the Abuja Food Security Summit; the 2007 Abuja Declaration on Fertilizer for the African Green Revolution; and the 2009 Sirte Declaration on Investing in Agriculture for Economic Growth and Food Security, among others. Reaffirming their resolve to advance the implementation of CAADP, African leaders adopted an ambitious goal that aims to eradicate hunger in Africa by 2025 within the context of a fully transformed agriculture system. The 2015 Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods (and the Implementation Strategy and Roadmap) sets the scene for a comprehensive package of directives to advance agricultural transformation and root out hunger in Africa. Key to the transformation process is the CAADP Results Framework to track progress, ensure accountability and assess results.

The importance of the resilience of livelihoods was recognized by African leaders in the Malabo declaration, in which they committed to reduce the vulnerabilities of livelihoods, notably: increasing the resilience of at least 30 per cent of farm, pastoral and fisher households to climate and weather-related risks by 2025; enhancing social security for rural workers and other vulnerable social groups; and mainstreaming resilience and risk management in policies, strategies and investment plans. The achievement of these targets will require the analysis of different farming systems to identify priorities and targets, and formulate action-oriented strategies for tangible results and impact.

Ultimately, strengthened institutions, incentives (for private and appropriate collective action) and policies must be aligned with the specific agricultural growth potentials of different farming systems. Land and water policies lie at the heart of effective resource management and rural development. Land reform has been common in Southern Africa and has been one attempt to exploit the inverse farm size-productivity relationship. It is widely recognized that small farms have high productivity, provided services are available. Growth Corridor approaches are now being implemented in a number of countries, often where it is presumed that the conditions exist for mining, commercial farming, forestry and manufacturing (Weng et al. 2013), for instance, in Northern Mozambique, in Southern Tanzania's maize mixed farming systems, and in Northern Ghana's cereal-root crop mixed farming system. Recently African governments have emphasized the potential for intra-regional markets (Badiane and Collins 2016) and have supported improved infrastructure, border facilities and regulations. Increased productivity, both total factor and partial, is an important goal for the agricultural sector.

From farm household strategies to development priorities and policies

Cross-scale and system linkages

The importance of linkages between farm households, communities, landscapes and value chains was noted earlier in the chapter. The institutions which function at each level influence the decisions and management at lower levels with both positive and negative

outcomes. For example, open grazing by many communities threatens the retention of crop residues on the soil surface to reduce soil erosion and the opportunity to establish high-yielding trees. However, government policies might change community practices. For example, regulations which encourage stall feeding and the control of grazing, with a view to the revegetation of degraded watersheds, might lead to an unintended positive outcome through the reduction of grazing pressure, thus enabling the retention of crop residues in the crop fields and diversification into tree enterprises.

In any community there is heterogeneity in farm households' characteristics and behaviour. Typical patterns of farm households' differences – small and large, young and old – can often be recognized throughout a particular farming system. From an institutional and social capital perspective, knowledge of the variation in family composition, stage in life cycle, status in the community and access to external networks of traders can be an advantage in designing watershed management or technology extension programs.

Linkages across farming systems occur through seasonal and annual movement of labour, livestock, water, nutrients and agricultural produce. Capital accumulated in one system is often reinvested in another system. Natural phenomena such as wind, rainfall and runoff, and human, livestock and wildlife movement contribute to the spread of weeds, pests and diseases across systems. Land and water use practices in upstream locations affect farming systems downstream. Transport systems and infrastructure (road, rail and waterways) have traditionally aided trade in agricultural products and inputs. In addition, there are new and emerging linkages promoted by ICT, trade liberalization, new markets, advances in logistics, transport systems, knowledge management and information exchange.

Water management at the farm level has interconnected livelihood, hydrological and ecological impacts at watershed and basin scale. This is because water is both an ecosystem 'good' and a 'service'. As an ecosystem good it provides drinking water, irrigation and hydropower. It also provides a range of ecosystem services – provisioning, regulating, cultural and supporting – that are often important to poor people's livelihoods (Millennium Ecosystem Assessment 2005). The externalities created by upstream water use often lead to conflicts between upstream and downstream communities. Water governance and institutional arrangements thus influence how well conflict is resolved and how equitable water sharing is between upstream and downstream users, while maintaining adequate environmental water flows to sustain ecological functions and deliver critical ecosystem services to both rural and urban households.

Nutrient practices at the household level can have a cumulative effect on farming systems and landscapes, including whether the nutrients are traded and distributed elsewhere. Policies and other drivers, meanwhile, affect household decisions. While nutrients are fundamental to ecosystem function and farming system intensification, in practice urban areas are concentrators of nutrients, partly via food supplies from rural areas and intensive peri-urban livestock production. Recycling solid waste and food wastes can be a crucial part of rural-urban linkages.

Livestock migrations between farming systems are common including transhumance. For example, herders migrate cattle between the agropastoral farming system and higher-potential mixed farming systems, and camel herders migrate between the arid pastoral oasis and the pastoral systems. There are economic, livelihood and resilience advantages to long-distance migration. However, negative side effects include the transmission of animal disease by livestock or by wild species, especially large mammalian herbivores in Eastern Africa. Migratory birds and mammals are also major agents spreading animal and human diseases.

In terms of biotic stress, insect pests which limit crop production (in all African farming systems) also cross farming system boundaries, for example sorghum midge. Plantain and banana are other examples, as they suffer from wind-dispersed pests and diseases, for example black sigatoka. Black pod disease on cocoa is spreading across West and Central Africa. Striga (*Striga hermonthica*) is a frequent parasitic weed of sorghum, millet and maize which has spread widely across Africa.

Framework for strategic interventions

The emergence of a new set of African leaders and stronger national commitments to sustainable development, supported by the New Partnerships for Agricultural Development (NEPAD) and CAADP, have been game changers. Complementary initiatives in rural education, women's empowerment and social capital have strengthened rural institutions. These recent investments in human capital, institutions and infrastructure are now reflected in improvements to food security and economic growth and in development indicators across the region. Farming systems development can contribute to Africa's broad-based transformation in the following ways:

- *Farming systems for improved food and nutrition security.* The vast majority of the hungry and food insecure reside in rural areas. Effective food systems require productive and resilient farming systems, thus farming and food systems are a part of designing and implementing zero hunger programs and effective social security nets – and these have to be differentiated for the different farming systems. Moreover, supporting diverse integrated farming systems facilitates diverse diets, which is associated with reduced malnutrition.
- *Farming systems for poverty reduction.* The majority of rural livelihoods in African countries are dependent on natural resources, including land and water. Some 70 per cent of Africa's poorest labourers are engaged in farming activities which differ by region. Therefore, farming system intensification must be tailored to local crops and livestock, which will generally increase farm labour productivity and reduce poverty. Moreover, to be effective, rural poverty reduction strategies for enhancing job creation, gender empowerment and entrepreneurship should be linked to existing farming and livelihood systems.
- *Farming systems for industrialization.* Industrialization has been identified by African leaders as a transformational path. Agribusiness and food processing will certainly boost agriculture and can help lift rural inhabitants out of poverty. Specific commodity programs can be tailored and targeted towards particular farming systems. In-depth analysis of farming systems, with a particular focus on backward and forward linkages and value-addition, can focus the investments on commodity and agribusiness potential.
- *Farming systems for adaptation to climate change.* The majority of livelihood systems in Africa are highly vulnerable to climate variability and climate change. Therefore, systematic analysis of farming systems can facilitate targeting, diversification and enhanced resilience of particular farming systems.

Knowledge of household responses to trends and interventions within different farming systems is essential information for developing effective public priorities and policies. Indeed, household strategies and development pathways can inform and underpin

Table 1.10 Examples of strategic interventions focused on household pathways

<i>Strategy intervention areas</i>	<i>Intensification</i>	<i>Diversification</i>	<i>Increased farm/herd size</i>	<i>Increased off-farm income</i>	<i>Exit from agriculture</i>
Population, poverty and food security (increased pressure)	Labour saving technologies	Labour- spreading enterprise mixes, diet education	Resettlement	Labour markets	Migration, land and livestock markets
Natural resources and climate (reduced availability and quality)	Climate-smart agriculture	Irrigation	Land tenure, water points for livestock	Secure land rights	Land for consolidation
Energy availability and use (slowly increasing availability, volatile prices)	Biomass	Renewables	Fuel for mechanization	–	–
Human capital, knowledge sharing and gender (improving availability of information)	Extension, technology training and information sharing	Farmer training in new crops or livestock, empowerment of women	Farm management training	Labour market information	Labour market information
Science and technology (improving varieties, breeds and practices)	Technologies for water and input use efficiency	New crops and livestock	Scalable technologies	Labour saving technologies, mechanization	–
Markets and trade (improving access)	Strengthening existing input and produce chains/markets	Fostering new input and produce markets	Improved access to finance	Functioning labour markets	Land and livestock markets, employment creation especially in rural areas
Policies and institutions (strengthening public goods)	Policies assisting input availability	New markets and inputs	Land tenure and sale/leasing markets	Labour markets, decentralization, transport	Migration

choices of strategic interventions. For example, diversification would generally require more investment in new market institutions than intensification of existing enterprise patterns. Moreover, the nature of required policy interventions will differ across farming systems, depending on the availability of infrastructure and complementary services such as finance. Table 1.10 provides a framework, with illustrations, for linking farm household pathways to possible strategic interventions for each of the seven drivers discussed earlier. These are developed further in each farming system chapter, where priority strategic interventions are highlighted in terms of the expected effects on farming system structure and function.

In general, the strategies of extremely poor farm households differ from those of somewhat better-off households. At the farming system level, the combination of strategies (in proportion to household types) provides an indication of household responses to market or policy changes. The mix of strategies also informs the targeting of agricultural policies to different farming systems, and to different groups within any particular farming system. Both aspects are important for productivity and for equitable development outcomes.

Guide for readers

Chapter 2 outlines the data sources and methods which were used for the farming systems characterization. The reader will have noted that the names of the fifteen defined farming systems are not capitalized. The analyses of the major farming systems are reported in Chapters 3–16, with chapters in declining order, generally, of the population of extremely poor. Chapter 17 summarizes the key potentials and cross-cutting issues. The ways forward are presented in Chapter 18 and the conclusions in Chapter 19.

Note

- 1 Conservation agriculture practices ensure minimum soil disturbance, year-round vegetative coverage of the soil surface and crop rotations, and are widely recognized as sustainable.

References

- Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., Kassie, M., Bogale, G., Tadesse, B. and Keno, T. (2015) Factors that transformed maize productivity in Ethiopia. *Food Security* 7: 965–981.
- Allan, W. (1965) *The African Husbandman*. Oliver and Boyd, Edinburgh/London, UK. Reprinted by International African Institute, Munster, Germany.
- Badiane, O. and Collins, J. (2016) Agricultural growth and productivity in Africa: Recent trends and future outlook. In Lynam, J., Beintema, N., Roseboom, J. and Badiane, O. (eds) *Agricultural Research in Africa: Investing in Future Harvests*. International Food Policy Research (IFPRI), Washington, DC.
- Cabrera, D. and Cabrera, L. (2015) *Systems Thinking Made Simple: New Hope for Solving Wicked Problems*. Odyssean Press, New York.
- Dixon, J. (2006) *Module 4: Investments in Sustainable Agricultural Intensification*. *Agricultural Investment Sourcebook*. World Bank, Washington, DC.
- Dixon, J., Gulliver, A. and Gibbon, D. (2001) *Farming Systems and Poverty. Improving Farmer's Livelihoods in a Changing World*. FAO & World Bank, Rome and Washington, DC, www.fao.org/farmingsystems/.
- Dixon, J., Hellin, J., Li, X. and Hyman, G. (2009) Review: Forty years of farming systems classification for enhanced food security and poverty reduction. *CABI Reviews* 4 (60): 1–14.

- Dorward, A. (2009) Integrating contested aspirations, processes and policy: Development and hanging in, stepping up and stepping out. *Development Policy Review* 27: 131–146.
- FAO (2015). *The State of Food and Agriculture 2010–2011*. FAO, Rome.
- FAOSTAT (various years), FAO database, FAO, Rome. www.fao.org/faostat/en/#data
- Faures, J.-M. and Santini, G. (2008). *Water and the Rural Poor: Interventions for Improving Livelihoods in Sub-Saharan Africa*. FAO, IFAD, Rome.
- Garrity, D., Dixon, J. and Boffa, J.-M. (2017) Understanding African farming systems as a basis for sustainable intensification. In Oborn, I., vanLauwe, B., Phillips, M., Thomas, R., Brooijmans, W. and Atta-Krah, K. (eds) *Sustainable Intensification in Smallholder Agriculture: An Integrated Research Approach*. Earthscan from Routledge, Oxford, pp 58–70.
- Haggblade, S. and Hazell, P. (eds) (2010) *Successes in African Agriculture: Lessons for the Future*. Johns Hopkins for IFPRI, Baltimore, MD.
- IFPRI (2015) 2014–2015 *Global Food Policy Report*. International Food Policy Research Institute, Washington, DC.
- InterAcademy Council. (2004) *Realizing the Promise and Potential of African Agriculture*. InterAcademy Council, Amsterdam, the Netherlands.
- Jayne, T.S. (2016) Megatrends transforming Africa's food systems: Getting ahead of the puck on policymaking. In African farmers in the digital age: Overcoming isolation, speeding up change, and taking success to scale. *Foreign Affairs*, Special Issue, New York.
- Malabo Montpellier Panel (2017) *Nourished: How Africa Can Build a Future Free from Hunger and Malnutrition*. Dakar, Senegal.
- MEA (Millennium Ecosystem Assessment) (2005) *Ecosystems and Human Well-Being: Health Synthesis*. World Resources Institute, Washington, DC.
- Norman, D.W. (2002) The farming systems approach: A historical perspective. *Proceedings of the 17th Symposium of the International Farming Systems Association. International Farming Systems Association*. Lake Buena Vista, Florida.
- Pingali, P., Bigot, Y. and Binswanger, H. (1987) *Agricultural Mechanisation and the Evolution of Farming Systems in Sub-Saharan Africa*. Johns Hopkins, Baltimore, MD.
- Qureshi, M.E., Dixon, J. and Wood, M. (2015) Public policies for improving food and nutrition security at different scales. *Food Security* 7: 393–403.
- Reardon, T. and Timmer, P. (2014) Five inter-linked transformations in the Asian agrifood economy: Food security implications. *Global Food Security* 3(2): 108–117.
- Robinson, T.P., Wint, G.R.W., Conchedda, G., Van Boeckel, T.P., Ercoli, V., Palamara, E. et al. (2014) Mapping the global distribution of livestock. *PLoS ONE* 9(5): e96084.
- Ruthenberg, H. (1971) *Farming Systems in the Tropics*. Oxford University Press, Oxford.
- Sinclair, F. (2017) Systems science at the scale of impact: Reconciling bottom up participation with the production of widely applicable research outputs. In Oborn, I., Vanlauwe, B., Phillips, M., Thomas, R., Brooijmans, W. and Atta-Krah, K. (eds) *Sustainable Intensification of Smallholder Agriculture: An Integrated Systems Research Approach*. Earthscan from Routledge, Oxford, pp. 43–57.
- United Nations Development Program (UNDP). (2015) *Africa Human Development Report (2015)*. UNDP, New York.
- Weng, L., Boedhihartono, A., Dirks, P.H.G.M., Dixon, J., Lubis, M.I. and Sayer, J. (2013) Mineral industries, growth corridors and agricultural development in Africa. *Global Food Security* 2(3): 195–202.
- World Bank. (2008) *World Development Report 2008. Agriculture for Development*. World Bank, Washington, DC.
- World Bank. (2015) *World Development Report 2015. Mind, Society and Behavior*. World Bank, Washington, DC.

2 Methods and data sources

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Key messages

- This book applies a unique, structured, systems methodology for characterizing and grouping large populations of farm households with broadly similar livelihood, production and consumption patterns, and for whom similar development strategies would be appropriate.
- As a result African households across the continent are grouped into 15 major farming systems and 58 subsystems.
- The farming systems analysis integrates an extensive range of spatial data, administrative statistics, assessment reports and expert knowledge, in order to update the African component of the 2001 FAO/World Bank farming systems analysis.
- Pattern recognition is key to teasing out the diversity inherent in African agriculture and in understanding common livelihood patterns (derived from crops, trees, livestock, fish and off-farm income), constraints and opportunities which define each farming system.
- The principle of central tendency is used to identify the core length of growing period and travel time to the nearest market town, which are two key indicators of access to agricultural resources and access to agricultural services, respectively, that shape livelihood patterns in each farming system.
- The method allows farming system drivers, trends and strategic interventions to be identified for policymakers, investors and research planners, using a synthesis of UN statistics, assessment reports and expert knowledge.

Summary

This chapter describes the farming systems analysis methodology used to characterize African farming systems in this book, in particular the methods for identifying a common livelihood pattern (derived from crops, trees, livestock, fish and off-farm income) and the constraints and development opportunities for each farming system. The analysis integrated a wide range of data and information from spatial databases, administrative statistics, assessment reports and expert knowledge of the particular farming system characteristics, drivers and trends, constraints and development opportunities. The skill of

pattern recognition is essential for identifying common mixes of system livelihoods. The farming system is shaped by access to agricultural resources (a basic indicator is length of growing period) and access to agricultural services (a basic indicator is travel time to the nearest market town), and these factors underpinned the mapping and characterization. The management and development of farming systems depend on the strategies of farm households for escape from poverty or improvement of farm incomes. The multidisciplinary analysis teams who identified the farming system constraints and opportunities, and the household strategies, subsequently wrote the relevant farming system chapters.

Overall approach

This chapter describes the methodology used for the characterization of the farming systems which are profiled in Chapters 3–16. The broad analytical approach is provided in the next section; thereafter the principal sources of data are listed and then the methods for delineation, characterization and grouping of farming systems and subsystems are presented.

The purpose of the farming systems framework is to inform science leaders and policymakers about the best options to accelerate the improvement of household livelihoods, food and nutrition security in the context of changing socioeconomic and climatic conditions. A number of principles underlie the analysis to ensure it is ‘fit-for-purpose’ for the farming systems framework.

These principles are:

- The analysis is at the African continental rather than national or sub-national levels.
- The analyses are based on rigorous, up-to-date and fit-for-purpose data and expert knowledge, for the nominated time period.
- There are pragmatic limits to the number of farming systems and, within each farming system, the number of subsystems.
- Information derived from spatial analysis, administrative statistics, reports, and expert and stakeholder knowledge is triangulated and integrated.
- Recognizing the natural heterogeneity in agriculture, each farming system is characterized according to its ‘central tendency’ in relation to livelihood pattern, access to agricultural resources and access to agricultural services.¹
- Interpolation and extrapolation is often required to fill gaps in knowledge for the chosen base year of 2015.

Spatial framework

In practice, the approach followed in this book identifies farming systems as a series of mappable regional entities or geographic zones. Regionalization is a widely recognized and applied geographic method of providing spatial frameworks, and it has numerous applications for the management of natural resources and policy development. Boundaries between regions are based on the best available data and knowledge and are analysed within an integrated multivariate approach.

The farming systems analysis traditionally includes broadscale livelihood patterns, climate and bio-physiographic patterns, plus regional and finer scale thematic socioeconomic data such as population density and market access. These data are analysed to identify farm household livelihood patterns across a variety of spatial scales. In this context, patterns

reflect a ‘central tendency’ for an identifiable farming system. Regionalization (which may or may not include social and economic elements) is an accepted international tool to assist in the delineation and characterization of ‘farming system’ level boundaries for planning, management and policy purposes (Werlen 2009).

Regions can be further differentiated into sub-regions using similar multivariate classifiers, often with a temporal and/or spatial dimension. An example of the spatial zoning process is the well-established practice of identifying agroecological zones with similar potential and constraints for use in development programs and for targeting of recommendations (FAO 1996).² Depending on the circumstances, zones often also relate to a period or point in time, for example areas affected by time-bound droughts. The way that a region or a farming system is differentiated depends on the parameters used, for example productivity, rainfall, farm size, crop–livestock pattern, or physical parameters such as elevation or soil type. These data are also used to identify the borders of each region or zone.

Farming systems approach

Farming generally depends on many components, including soil and water resources, plant and animal production enterprises, and the farm household. Collectively these may be viewed as an integrated system. The term farm household system is often applied to the individual farm unit, and the term farming system to collections of similar farm household units. There are always interactions between the components and with the local external environment including climate, the surrounding landscape and local institutions, including markets (Figure 1.2). Farm households are often complex and dynamic units reflecting the management of agricultural resources by farmers to produce food and fibre.

The Farming Systems Approach (FSA) used in this study had its origins in the early 1960s in Central America and Africa where it was used to examine the complexity of smallholder farming systems for both research and development (R&D) purposes. Over the past 50 years, the FSA has evolved markedly (Dixon et al. 2009), as illustrated in Table 2.1. Today the term has achieved wide currency in public policy, strategy and scientific documents. The early applications of FSA were dominated by productivity, sometimes with a commodity focus, for example rice or cattle. The scope of the FSA expanded gradually from the 1980s, placing increasing emphasis on horizontal and vertical integration, including multiple sources of household livelihoods, the role of the community, plus the biophysical environment and support services. Through incorporating these interactions, the use of the FSA as an analytical framework has contributed to a paradigm change in rural development thinking, research and policy development.

The focus on the farm household at the heart of resource allocation decisions benefited from the Sustainable Livelihoods Approach (SLA) (Ellis 2000), and thus, farm household typologies have been widely applied. During the first decade of this century there was increased interest in the use of the FSA in R&D including marked shifts towards holistic perspectives and learning approaches, improved livelihoods, and greater household food and nutrition security, whether through technology, markets or policy. New development themes have also been incorporated such as gender, indigenous knowledge, social networks, community management, local institutions, information and adaptation to climate change. Concurrently, analytical techniques have become more participatory, more interdisciplinary and transdisciplinary, with increasing attention to experimentation, monitoring and impact assessment.

Table 2.1 Evolution of the farming systems approach

Characteristics	1970's	1980's	1990's	2000's	2010's
System Level:					
Farm					
Household					
Groups/Community					
Watershed, Landscape					
National, Regional					
Livelihood Focus:					
Crops					
Crop-Livestock					
Multiple Household Livelihoods					
Value Chains					
Innovation System Focus:					
Research					
Research & Development					
Policy & Planning					
Stakeholder Focus:					
Public					
Public & Civil Society					
Public, Private & Civil Society					
Policy Focus:					
Agricultural Productivity					
Natural Resource Management & Climate					
Market Access & Trade					
Other Emphases:					
Gender					
Poverty Reduction					
Food & Nutrition Security					
Climate Smart Agriculture					

Source: Adapted from Dixon et al. (2001).

Farming systems classification

As noted in Chapter 1, systems principles have been applied to the analysis and classification of farming for at least a century. Systems thinking helps to generate typologies of farming systems and distinct zones or agricultural regions. In order to usefully inform science and policy leaders, careful analysis is required to: identify the most useful definitions of farming systems; define the core characteristics or 'central tendency' of each farming

system; and identify clear spatial boundaries given the challenges presented by the high level of natural heterogeneity within any given country or area. The system boundary is a critical construct which determines the extent and subsequent characterization, description and analysis of the farming system. However, this farming systems analysis recognizes (and indicates on maps) the gradual transitional zones between pairs of farming systems.

The classification and mapping of farming or agricultural systems has a long history (reviewed in Dixon et al. 2009). Farming systems (and farming systems research) methodology has evolved and improved over time as the understanding of systems approaches has progressed (see, for example, Darnhofer et al. 2012). In this respect the FSA is often viewed as a ‘soft systems’ approach that spans biophysical and social science disciplines and is focused on both system resilience and productivity, and people and their livelihoods (Packham et al. 2007).

Traditionally, farming systems can be viewed as a hierarchy or set of component elements within which certain processes and interactions occur at specific levels. In the current analysis, a farming system is defined as a population of farm households, often of mixed sizes and types, that as a group has broadly similar patterns of resources, livelihoods, consumption, constraints and opportunities, and for which similar development strategies and interventions would be appropriate. In a generic sense, a farming system is a spatial concept which is located within the contexts of a wider social system (for example a village) and a wider landscape or ecosystem. Farming system zones can be nested, subsuming farming subsystems, and combined into regional groupings of similar farming systems, depending on the purpose of the analysis. With its focus on food and nutrition security, this book recognizes groups of farming systems with high, medium and low potential for improvement of household food and nutrition security by 2030 (a timeframe which aligns with several international development frameworks and the Malabo Declaration).

A central tenet of the FSA adopted for the current study is that the identification, delineation, characterization and analysis of systems within which smallholder households live and make resource management decisions, provide powerful insights for policymakers and science leaders. Results of the analysis can be used to inform the development of strategic policies and priorities for the improvement of food and nutrition security, as well as other goals (for example, rural transformation, export earnings, import substitution, poverty reduction and responding to threats such as increased climate variability). It should be noted that poverty and household food insecurity are closely associated and often correlated. In this sense, the delineation and characterization of the major farming systems provide a useful framework within which to develop and assess agricultural development strategies and interventions (including adaptation to changing market conditions and climate change).

Policymakers and science leaders, who are a major target audience of this analysis, often need relatively broad and large-scale findings (and insights on trends) to guide policy, planning and program development. Scientists and modellers investigating alternative technological and institutional pathways to sustainable development at the continental or national levels (and the Sustainable Development Goals (SDGs)) also need a broad framework for their analyses. Similarly, academics and educators can benefit from a simple, consistent continent-wide classification system enabling cross-border comparisons. As such, many high-level users demand a structured farming systems framework with a workable number of broad farming systems defined at the continental level. Logically, such a farming systems framework would contrast resource access, market access, livelihood patterns

and strategic interventions. Such a farming systems framework across Africa fosters the exchange of relevant research results and policy experience across countries for any particular farming system.

In addition, for some audiences, a disaggregation of each broad farming system is valuable for further analysis. Therefore, for most of the farming systems, a number of subsystems were identified based on relevant parameters such as combinations and proportions of crops in the cropping system, level of intensification, access to agricultural services, agroecological conditions, or clusters of countries (as a potential basis for support to national policymaking). In nine farming systems the subsystems are mapped, but in six of them (including the urban and peri-urban farming system) the subsystems are defined and characterized but not mapped due to issues of scale, ease of implementation and spatial data availability.

Sources of information

One of the core principles of the analysis is the integration (or triangulation) of information derived from several sources, for example spatial analysis results, administrative and survey data, and expert and stakeholder knowledge. Triangulation has many advantages, not least to deal with gaps in datasets and different measurements used by the variety of sources of data and other information. The updating of the 2001 farming system characterization and trends (from Dixon et al. 2001) was undertaken by multidisciplinary teams, one for each farming system, involving a total of 65 scientists and development professionals with in-depth, field knowledge of relevant African agricultural systems who integrated data from different sources.

The analysis reported in this book sourced the best available spatial data from FAO, IIASA, IFPRI, University of Minnesota, CIESIN, ITC, ICRAF, AfriPop and the Centre for World Food Studies at Vrije University, Amsterdam (Merbis and Wesenbeek 2012). FAO's Global Agroecological Zones (GAEZ) and IIASA's databases provided agricultural resource quality data. IFPRI and the University of Minnesota's Harvest Choice database and IIASA's spatial databases contained crop extent and production. Human population density was derived from CIESIN and AfriPop. Livestock distributions were derived from FAO and Oxford University. Other critical spatial data included transport infrastructure to estimate travel time to markets, and poverty. The core spatial databases used in the analysis are listed in Table 2.5.

In the process of characterizing the selected farming systems, a considerable amount of reconciliation across datasets was required. There were often anomalies between variables, for example between spatial and administrative datasets at national and regional levels of aggregation, and between computed ratios from datasets such as population density, farm and herd size, and crop-livestock ratios, especially when computed for pixels (small land areas of approximately 8–10 km²) from the original spatial surfaces. Anomalies sometimes required reference to third sources of data. Computations assisted with the assessment and correction of the original datasets – a process often appreciated by the institutional owner of the dataset. Collectively the above data were used to check the spatial information for the characterization of farming systems and subsystems. Compared with the original study in 2001 (Dixon et al. (2001), which delineated the original geographical boundaries of farming systems, the checking and revision of farming system characterization, boundaries and trends were much simpler tasks in this analysis.

A second source of information was a series of outlook, synthesis and foresight documents and thematic and panel reports (Table 2.6). These data and knowledge sets were sourced from AU, NEPAD-AU, UNECA, FARA, African Development Bank, and the World Bank, IFAD, CGIAR and other international development organizations.

The third major source of information was the expert knowledge of a large number of individuals. These experts included members of multidisciplinary systems analysis teams who had personal experience with the farming systems under consideration (see list of Contributors), other experts who offered project maps at national or regional scale and who provided advice in relation to the delineation of farming systems (Table 2.7), and the book editors. Experts provided access to crop distribution, agroecological zone and farming systems maps developed by secondary sources such as national or regional projects. The Famine Early Warning Systems Network (FEWS NET) livelihood zone maps provided valuable references for system delineation and characterization in eastern and southern Africa. FEWS NET's definition of a livelihood zone – an area within which people share broadly the same pattern of livelihood, including options for obtaining food, and income and market opportunities – correlates with the definition of farming systems used in this book. The collective expert judgements informed identification of drivers, trends and strategic interventions for each farming system.

The current farming system analysis highlighted a number of critical weaknesses in datasets. For example, there is low coherence and consistency across datasets which were collected for specific purposes, often using different metrics. Variable trends and system development pathways are rarely well documented. The distinction between, and comparison of, cropping systems under single-season and bimodal rainfall patterns are often challenging. There are differences between datasets from interpolated data (such as the P/PET and length of growing period (LGP) datasets) and sensor-based products (noting that the rigour of sensor products in areas with less than LGP 90 days, or in areas with very high cloud cover, is limited). Sensor products can provide good bimodal information that may not be found within the interpolated datasets.³

Methods for characterizing African farming systems

Overview

A multidisciplinary team of experts with personal knowledge and on-the-ground experience was appointed to author the updates to the characterization and analysis of each farming system, with the support of the data analysts and book editors. When necessary, other key informants were also involved to fill gaps in knowledge and to advise on local system trends. The focus in this analysis was the revision of 2001 farming systems, rather than the identification of new farming systems. A three-step, iterative, expert-driven process incorporating underlying thematic datasets and expert knowledge was used to update and refine the spatial delineation of systems identified in 2001 (Figure 2.1). The same process was used to identify, delineate and characterize subsystems.

Dixon et al. (2001) identified 15 discrete farming systems within sub-Saharan Africa (SSA) and 8 within North Africa based on the concept of central tendency (see earlier). With the exception of urban-based farming systems (and coastal artisanal fishing in

Figure 2.1 Approach to farming systems identification and characterization.

North Africa), all were spatially delineated and mapped (Figure 2.2a and b). The 2000 farming system boundaries were delineated based on the following parameters:

- Dominant pattern of farm household livelihoods, including field crops, livestock, trees, aquaculture, hunting and gathering, processing and off-farm activities. These are shaped, in turn, by the following two parameters:
 - Access to agricultural resources – including water, land (including farm size), grazing areas and forest (extent and type); climate, of which altitude is an important determinant; landscape, including land tenure and organization.
 - Access to agricultural services, including input and produce markets, notably access to seed, agrochemicals, machinery and information, financial, insurance and veterinary services, as well as outlets for surplus grain and livestock produce, and off-farm employment opportunities.

The present study commenced by checking the characterization of the 2000 farming systems against the realities on the ground in 2015. The check drew on spatial databases of crop and livestock distributions (from FAO and the IFPRI/University of Minnesota Harvest Choice databases) and administrative statistics (from FAOSTAT and key informants – see information sources in Table 2.7). Over the period from 2000 to 2015, there were many changes in rural population density, access to agricultural services and technology choices. It is for this reason that the analysis devoted considerable effort to understanding and documenting the seven drivers of change and trends in farming system characteristics (see discussion later). Many farming systems had evolved in a predictable fashion with increased population density, reduced farm size and changed cropping pattern – in other words, the characterization needed to be updated. In other

farming systems the institutional or market access conditions had changed so much that the livelihood pattern, constraints and opportunities had changed significantly. In these cases, the farming systems were apportioned to other existing farming systems, or new systems were created. In the process, most of the North African farming systems were associated with one or another of the 2001 SSA farming systems because of similar livelihood patterns, agricultural resources and access to agricultural services. As Figure 2.1 indicates, the steps for identification and characterization were iterative.

Figure 2.2a and b contrasts the map of the 23 farming systems in 2000 (15 in SSA; 8 in North Africa) with the map of the 15 revised, consolidated and updated farming systems in 2015. The distributions of cultivated land, particular crops and livestock, and forests across the African landscape, sourced principally from spatial datasets, administrative data and key informants, were particularly important elements to guide the understanding of livelihood patterns by farming system in 2015 – and the changes from 2000. A number of other indicators of livelihood patterns were also useful, including crop and livestock

Figure 2.2a Map of farming systems of Africa in 2000.

Note: The 2000 map is a composite of SSA and North Africa maps in Dixon et al. (2001).

Figure 2.2b Map of farming systems of Africa in 2015.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Note: Because of lack of comparable data, the urban and peri-urban and the island farming systems were not mapped in either 2000 or 2015.

production levels. The urban and peri-urban and the island farming systems were characterized but not mapped in 2015. In the 2015 analysis, a total of 58 subsystems were named and characterized briefly or fully; and of these 42 were delineated and mapped in 10 farming systems (as will be described in Chapters 3–16).

The main changes were the merger of the North African systems with equivalent SSA farming systems; the reclassification of the dualistic smallholder and large commercial farming in southern Africa to, largely, maize mixed and perennial mixed farming systems; and the reduction in extent of the forest-based farming system because of population pressure, loggers' tracks and demand for root crops. The maize mixed system has expanded into coarse cereal and root crop farming in Central Africa, and the cereal-root crop mixed farming system has contracted to its heartland in the west and central African savannah.

Because of the expansion of population and cropping in pastoral areas, the agropastoral system has expanded in several parts of Africa. Similarly, the strengthening of markets has led to the conversion of some maize mixed farming to the commercial smallholder high-land perennial system. Thus, as livelihood patterns evolved, the system boundaries had to be checked and revised where appropriate.

Access to agricultural resources

The first of two major factors shaping the livelihood patterns of farming systems was access to agricultural resources within the farming system (Dixon et al. 2001). Both quantity and quality of access, and the resources themselves, need to be considered. The combination of population density and agricultural resource availability shape farm size, or family access to grazing land. While population has grown by about one-third during the period 2000 to 2015, farm size has diminished (Chapter 1). Population density varies considerably across Africa, as shown in Figure 2.3. There are hotspots of high density in the Ethiopian highlands, around the East African Rift Valley Lakes, and in western and in north-western Africa; these place great pressure on farm land and water resources.

Figure 2.3 Map of total population density in Africa in 2015.

Source: AfriPop.

The second aspect of agricultural resources is quality. A number of key parameters were used to define the quality of resources of a farming system (including LGP,⁴ elevation, environmental constraints), and to inform each farming system expert group during the process of identifying the system's 'central tendency' and the location of its boundaries. LGP is a fundamental component of agroecological zones (AEZ)⁵ that reflects aspects of climate, soils and landform, and may be considered a surrogate for farm natural resource quality. In this respect, LGP was a key defining parameter for a number of farming systems. The ranking of systems by 30-day LGP intervals gives an intuitively expected sequence in many instances (Figure 2.4). In some cases different farming systems have similar distributions of LGP, for example root and tuber crop farming system and the highland perennial system, where the difference is explained by completely different land use and livelihood patterns – the highland perennial farming system has greater elevation, better access to agricultural services and higher population density than the root and tuber crop system. Similarly, elevation and terrain explain the differences in livelihood pattern between the highland mixed and the maize mixed farming systems which have similar LGP distributions.

As shown in Figure 2.5, boundaries of some farming systems such as arid pastoral, pastoral, agropastoral, forest-based farming systems align rather neatly in many, but not all, areas, with the underlying 30-day interval LGP dataset from IIASA/FAO, indicating a similar progression for the second classification indicator, access to agricultural services. In other farming systems, for example the highland perennial farming system, the access to agricultural services was a stronger determinant of livelihood patterns and boundaries than LGP.

As explained earlier, characterization of areas with bimodal growing cycles is more difficult. A separate data source, other than the LGP layers from IIASA/FAO, was used to inform parameters in areas that experience a bimodal growing cycle such as in the Horn of Africa (Vrieling et al. 2011, 2013). Satellite remote sensing data was used

Figure 2.4 Distribution of length of growing periods by farming system (%) in sub-Saharan Africa. Source: van Velthuis unpublished (2015) and van Velthuis et al. (2013).

to provide bimodal information that was not found within the interpolated datasets. Figure 2.6 shows the average LGP for uni- and bimodal growing cycles for Africa based on this data. Note that areas along the Guinea Coast considered bimodal were masked out due to cloud contamination which impacted the accuracy of LGP values.

Several other parameters including irrigation, elevation (for example, in the case of highland systems), net primary productivity and environmental criteria such as soil type and depth (in the case of tree crop systems) also assisted with system characterization and delineation. In all cases, datasets and maps were subjected to extensive peer review to assess their fitness for purpose and confirm their utility. Consultations took place during several project workshops, email communications as well as numerous Skype and telephone consultations. As a result, in many cases no single dataset was used to define farming system boundaries, but rather a combination of different datasets, supporting maps, administrative statistics and expert knowledge were used iteratively to characterize and delineate farming systems.

Figure 2.5 Map of 30-day interval LGP with farming systems delineated by a red line.

Source: van Velthuis unpublished (2015) and van Velthuis et al. (2013).

Note: Numbers denote different farming systems.

Figure 2.6 Remotely sensed (1981–2011) derived average 30-day length of growing season data for two growing cycles. First season on left and second season on right.

Source: Vrieling et al. (2011, 2013).⁶

Most farming system zones span a range of values for key selected parameters, for example annual LGP days. Figure 2.7 shows that the LGP central tendency for the maize mixed and agropastoral farming systems clearly lies in given intervals, whereas other systems, for example the fish-based system, are less influenced by LGP (rather, they are influenced by access to fishing waters and markets). In this context, when dealing with parameters which are monomodally distributed and not excessively skewed, authors have

Figure 2.7 Relative distribution of 30-day LGP intervals in selected farming systems.

generally characterized the farming system by parameter values which embrace approximately two-thirds of the parameter observations.

Access to agricultural services

The second major factor in the identification of farming systems was access to agricultural services (Dixon et al. 2001), in particular value chains, and access to markets for inputs such as seed and fertilizer and to produce such as grain or livestock. This variable also includes aspects of market quality such as diversity of inputs or produce marketed, competitiveness of markets, integration with national and regional markets, degree of organized group marketing and finance availability, as well as diversity and quality of public and private service provision, such as mobile phone coverage, market information availability, extension and veterinary services.

Using spatial data on roads of various standards and town populations, it was possible to estimate approximate travel time to major market towns such as cities with a population of 50,000 or more, as shown in Table 2.2, as well as the overall access to agricultural services for each farming system.

There is a wide variety of agricultural services which are essential for the development of farming systems. Knowledge of technologies and market prices is as important as access to inputs or produce markets. Increasingly, information services such as mobile phones, other ICT services, TV or radio are a critical determinant of livelihood options. These communications technologies supplement, and might in time supplant, traditional public agricultural extension services. Such services complement the physical access to markets for inputs and produce. In this analysis, one quantitative indicator of access to agricultural services is travel time to major market cities with a population

Table 2.2 Access to agricultural services for African farming systems

<i>Farming system</i>	<i>Access to agricultural services</i>	<i>Average travel time to nearest town with population 50,000 or more (hrs)</i>
Maize mixed	Medium	8.3
Agropastoral	Low-medium	7.1
Highland perennial	Medium-high	5.6
Root and tuber crop	Medium	8.8
Cereal-root crop mixed	Medium-high	7.3
Highland mixed	Low-medium	7.1
Tree crop	High	4.7
Pastoral	Low	8.3
Fish-based	Medium-high	5.0
Forest-based	Low	13.7
Irrigated	High	3.8
Arid pastoral and oasis	Very low	20.8
Perennial mixed	High	3.8
Island	Medium	na
Urban and peri-urban	Medium-high	na

Sources: Joint Research Centre – Global accessibility data (travel time to major cities) and expert judgements.

Notes: na = not available.

of 50,000 or greater. These estimates are based on composite maps of infrastructure but face the challenges of lack of standard classification for rural markets and types of roads across Africa. Moreover, the level of competition in rural markets is often low, and thus market agents often exert asymmetric power over farmers so that they drive down grain and livestock prices and elevate prices for uncontrolled inputs. All considered, the authors have provided low/medium/high ratings for overall access to agricultural services, which are guided by, but not exactly correlated with, the estimated travel times to market cities. For instance, although road density indicates moderate proximity of the pastoral farming system to markets, this has not necessarily led to competitive markets for a broad range of agricultural inputs and other agricultural services, and thus the system is rated as low access to agricultural services.

Figure 2.8 plots the values for travel time to market (a town with 50,000 population) within selected farming systems, by frequency of values. The actual travel time spatial layer (map) used in the farming system analysis is presented in Figure 2.9.

Key characteristics of farming systems in 2015

Fundamental to purposeful classification is the identification of the users and their needs – in this case agricultural policymakers and science leaders – and the way in which a defined

Figure 2.8 Travel time to town with population of 50,000 in selected farming systems.

Source: Joint Research Centre – Global accessibility data (travel time to major cities).

Figure 2.9 Map of travel time to 50,000 town and farming systems boundaries.

Source: Joint Research Centre – Global accessibility data (travel time to major cities).

Note: Numbers denote different farming systems.

group of farming systems could inform and improve agricultural policymaking, research and investment priorities.

Bringing together the information on livelihood patterns, access to agricultural resources and access to agricultural services enables readers to understand the core characteristics of the 15 farming systems depicted in Figure 2.2a and b for 2015. Key characteristics of the farming systems are presented in Table 2.3, with emphasis on access to agricultural services and agroecological zones.

Following the style of the 2001 FAO/World Bank study, the names of farming systems are broadly based on the main household livelihood resources (crop type and reliance on livestock (including fish), supplemented by other salient characteristics such as rainfed or irrigated production, agroecology (perennial, arid), altitude (highland or lowland) and location/infrastructure (urban).

In Chapters 3–16, each of the 15 farming systems is characterized, in summary form, by one basic data table. Table 2.4 lists the data sources for the ‘basic data’ tables and the methods used to estimate or compute the information for each of the farming systems. In many instances, combinations of spatial data and administrative statistics were effective in

Table 2.3 Key characteristics of 2015 African farming systems

<i>Farming system</i>	<i>Travel time to 50,000 town</i>	<i>Access to agricultural services</i>	<i>LGP core range (days)</i>	<i>Average LGP</i>	<i>Agricultural population (million)</i>	<i>% poor (SSA)</i>
Maize mixed	8.3	Medium	Sub-humid 150–240	196	107	22.0
Agropastoral	7.1	Low–medium	Moist semi-arid 75–165	130	98	18.6
Highland perennial	5.6	High	Sub-humid/ humid 240–330	267	61	11.0
Root and tuber crop	8.8	Low–medium	Sub-humid/ humid 210–300	269	50	10.9
Cereal–root crop mixed	7.3	Medium–high	Moist semi-arid/sub-humid 150–210	187	43	10.3
Highland mixed	7.1	Low–medium	Moist semi-arid/sub-humid 150–270	183	45	6.2
Tree crop	4.7	High	Humid 270–330	299	30	6.0
Pastoral	8.3	Low	Arid/dry semi-arid 30–90	64	38	4.5
Fish-based	5.0	Medium–high	Various 150–330	197	22	4.1
Forest-based	13.7	Low	Humid 330–365	343	12	2.5
Irrigated	3.8	Medium–high	Irrigated 0–90	54	48	3
Arid pastoral and oasis	20.8	Very low	Arid 0–30	12	8	0.5
Perennial mixed	3.8	High	Moist semi-arid/sub-humid 150–240	185	12	0.6
Island	na	Medium	Various	–	4	–
Urban and peri-urban	na	Medium–high	Various	–	–	–

Sources: Based on existing data and author expert judgments.

Table 2.4 Data source and estimation methods for basic farming system data tables

Item

- Data source
 - Estimation method
-

Total human population (million)

- Source: UN Pop Div, CIESIN, FAOSTAT and others.
 - Projections for 2015 were based on linear regression using data points from 2000, 2005, 2010 and 2014.
-

Agricultural population (million)

- Source: Computed from rural population (UN Pop) and FAOSTAT.
 - For North Africa (NA), AfriPop 2010 was used as a spatial footprint, and agricultural population was estimated from rural population with the following coefficients: 0.9 for NA pastoral and arid pastoral, and oasis farming systems (low population density); 0.85 for NA highland mixed, rainfed mixed and dryland mixed farming systems (medium population density); and 0.8 for NA large-scale irrigated farming systems (high population density). High population density areas have relatively greater size and prevalence of rural towns. In contrast, low population areas have fewer rural towns and a higher proportion of agricultural population.
 - For sub-Saharan Africa FAOSTAT and Harvest Choice data were used.
-

Total system area (million ha)

- Source: system generated.
-

Cultivated area (million ha; % of total)

- Source: FAO/IIASA GAEZ version 3* – Harvest Choice, IFPRI and Ramankutty.
-

Irrigated area (million ha; % of cultivated)

- Source: FAO Global Map of Irrigation Areas – version 5, Harvest Choice and IFPRI.
-

Total livestock population (million TLU)

- Source: FAO Gridded Livestock of the world, FAOSTAT FAO/IIASA GAEZ version 3 – Harvest Choice and IFPRI.
 - Tropical Livestock Units (TLU) are livestock numbers converted to a common unit. Conversion factors are: cattle = 0.7, sheep = 0.1, goat = 0.1, pig = 0.2, chicken = 0.01. Factors taken mostly from www.lrrd.org/lrrd18/8/chil18117.htm, except for cattle. See also http://en.wikipedia.org/wiki/Livestock_grazing_comparison.
-

Major agroecological zone

- Source: FAO/IIASA GAEZ version 3 – Harvest Choice and IFPRI.
-

Length of growing season (average, days; core range, days)

- Source: FAO/IIASA GAEZ version 3.0 – Harvest Choice.
 - Average LGP is the average length of growing period tied to pixels where a given farming system occurs.
 - Core range refers to the boundaries of contiguous 30-day LGP intervals where at least two-thirds of the farming system occurs.
-

Access to services, including markets (low/medium/high)

- Source: Author estimates of general access to services in the farming system based on market access and quality, and other services such as diversity and quality of public and private service provision, such as mobile phone coverage, market information availability, extension and veterinary services, availability of finance.
-

(continued)

Table 2.4 (continued)

Time to market (average, hours; core range, hours)

- Source: Joint Research Centre – Global Accessibility map for continental Africa. Harvest Choice and IFPRI for sub-Saharan Africa.
- Average distance is the average travel time to a town of 50,000 inhabitants tied to pixels where a given farming system occurs.
- Core range refers to the boundaries of travel time intervals (0; 0–1; 1–2; 2–4; 4–6; 6–10; > 10) where at least two-thirds of the farming system occurs.

Agricultural population density (persons/total ha; persons/cultivated ha)

- Agricultural population divided by total and cultivated area.

Livestock density (TLU/total ha; TLU/cultivated ha)

- Computed from above data;
- TLU tropical livestock unit conversions are cattle 0.7, sheep 0.1, goat 0.1, pig 0.2, chicken 0.01.

Standard farm household size (cultivated ha; TLU)

- Source: same as above.
- Farm size: cultivated area divided by number of households (agricultural population divided by mean household size of 5.5).
- Herd size: livestock population divided by number of households (agricultural population divided by 5.5).

Extreme poverty (approx. % of rural population)

- Source: Harvest Choice for SSA; World Bank for national data in North Africa.
- Spatial data on poverty incidence in North African systems were not available, thus administrative data and other estimates were referred to in the characterization of the farming systems.

* FAO/IIASA GAEZ version 3.0 was used for all analyses except for Figure 2.4.

deriving robust parameter estimates. In some instances, the convergence of several spatial databases (or administrative statistics databases) underpinned estimates for the basic data table. Where ratings are given (such as low/medium/high market access), the underlying parameter ranges are given in the relevant section or table.

Approaches to the analysis of drivers and trends

As shown earlier, there have been major changes over the period between 2000 and 2015. In order to characterize the drivers of change and the implications for farming systems, Dixon et al. (2001) identified six major drivers of change in farming systems. The present analysis added one additional driver, namely energy, to make seven drivers in all. These are:

- 1 population
- 2 natural resources and climate
- 3 energy
- 4 human capital, information and gender
- 5 science and technology

- 6 trade and markets
- 7 policies and institutions

Chapter 1 discussed the foresight studies, assessment reports and trend analyses which can inform the strength of the drivers and the trends and the implications for the farming systems. There is a paucity of detailed analyses or modelling of future trends. In reality, farming systems and rural economies are inherently complex, and so the focus in this analysis has been on identifying major drivers and the implications for strategic interventions for rural development.

With changes in population, infrastructure and technology, both the classification and the extent of several farming systems have changed since 2001. For instance, the area in the rice tree crop farming system in Madagascar has now been distributed between the tree crop and various other systems. Similarly, and for the purpose of consistency in approach to farm enterprise patterns, access to agricultural resources and access to agricultural services were the basis for other farming systems changes noted in Figure 2.2.

Taken together, the seven drivers of change are also causing incremental adjustments to system structure and composition, many of which were anticipated in Dixon et al. (2001). Some changes are visible in terms of new livelihood patterns (for example, adoption of pigeon pea, small-scale irrigation or tree establishment in food crop fields in the maize mixed system). Some other changes might be largely invisible (for example, declining soil fertility in the perennial mixed system, and the strengthening of social capital with farmer-managed natural regeneration in the Sahelian agropastoral system). For example, the combination of accessible and well-developed markets for maize, lower labour requirements for its production and processing, lower bird depredation, and its suitability in the staple dish has stimulated expansion of maize in the eastern and southern agropastoral and other farming systems. Market development has expanded the opportunities for smallholders in East Africa, in particular in horticulture and dairy. Careful observers and analysts can predict future changes.

Household strategies

All farming system chapters evaluate the relative importance of household strategies for reducing hunger and poverty, and enhancing livelihoods and incomes; these strategies directly support improved household food and nutrition security. In the relevant table in each chapter, the relative importance of household strategies for the 2000–2015 period has been drawn from Dixon et al. (2001). The multidisciplinary teams estimated the relative importance of these five strategies (Chapter 1) for reduction of poverty of the extremely poor (living on less than US\$1.90 per day) and the improvement of household livelihoods for the less poor for the period 2015 to 2030. Population-weighted averages of the strategies were computed for the region and also for various groupings of farming systems (see next sub-section).

Grouping farming systems

Groupings of farming systems can serve different purposes. For example, all systems which depend on livelihoods from livestock could be grouped. The ultimate purpose of analysing such groupings is to improve food and nutrition security strategies. For ease of use by

regional decisionmakers, in Chapter 17 the 15 farming systems are grouped into 3 categories (low, medium and high) of household food security potential for the year 2030, taking into account access to agricultural resources (including farm size and LGP) and access to agricultural services (including degree and quality of market access and opportunities for off-farm income).

Notes

- 1 In statistics a central tendency is a central or typical value for a probability distribution and relates to the tendency of quantitative data (or systems) to cluster around a central value.
- 2 See www.fao.org/docrep/W2962E/w2962e-03.htm.
- 3 A significant issue when modelling LGP from climate station data for Africa is the sparse distribution and maintenance of weather stations. This impacts the rigour and availability of consistent data and thereby limits identification and analysis of areas with bimodal characteristics. An alternative approach based on multi-temporal remote sensing data enables identification of start- and end-of-season parameters and as a result it is possible to identify and characterize areas with bimodal seasonal growing activity (Vrieling et al. 2013).
- 4 See www.fao.org/nr/climpag/cropfor/lgp_en.asp.
- 5 See www.fao.org/docrep/W2962E/w2962e-03.htm.
- 6 See <http://link.springer.com/article/10.1007%2Fs10584-011-0049-1>.

References

- Darnhofer, D., Gibbon, D. and Dedieu, B. (eds) (2012) *Farming Systems Research into the 21st Century: The New Dynamic*. Springer.
- Dixon, J. and Gulliver, A. with Gibbon, D. (2001) *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World*. FAO and World Bank.
- Dixon, J., Hellin, J., Li, X. and Hyman, G. (2009) Review: Forty years of farming systems classification for enhanced food security and poverty reduction. *CABI Reviews* 4(60): 1–14.
- Ellis, F. (2000) *Rural Livelihoods and Diversity in Developing Countries*. Oxford University Press.
- FAO (1996) *Agro-Ecological Zoning Guidelines*, FAO Soils Bulletin 73. Soil Resources, Management and Conservation Service, FAO Land and Water Division.
- FAOSTAT (n.d.) FAO agriculture database, FAO, Rome. www.fao.org/faostat/en/.
- Merbis, M.D. and van Wessenbeek, C.F.A. (2012) *Africa in Maps: Data Repository of the Food Economy of Sub-Saharan Africa*. Centre for World Food Studies.
- Packham R., Petheram, J. and Murray-Prior, R. (2007) A farming systems research (FSR) as a platform for RD&E in agriculture and NRM. In *APEN Forum 2007, Capture, Consolidate and Communicate: The Changing Nature of Extension*. Canberra, 13–14 November 2007, Australasia-Pacific Extension Network, www.apen.org.au/images/PDF%20documents/APEN%20Forum07%20papers/Packham_Petheram__Prior__A_Farming_Systems_Research_%28FSR%29_As_a_Platform_for_RDE_in_Agriculture_and_NRM.pdf.
- van Velthuisen, H., Fischer, G. and Hizsnyik, E. (2013) *Technical Annex: FS Characterization with GAEZ Data*. The African Farming Systems Update Project. IIASA.
- Vrieling, A., Beurs, K.M. and Brown, M.E. (2011) Variability of African farming systems from phenological analysis of NDVI time series. *Climate Change* 109(3–4): 455–477.
- Vrieling, A., De Leeuw, J. and Said, M.Y. (2013) *Length of Growing Period over Africa: Variability and Trends from 30 Years of NDVI Time Series*. www.mdpi.com/2072-4292/5/2/982/pdf.
- Werlen, B. (2009) Structurationist geography. In Kitchin, R. and Thrift, N. (eds) *International Encyclopedia for Human Geography*. Elsevier.
- Zomer, R.J., Trabucco, A., Coe, R. and Place, F. (2009) *Trees on Farm: Analysis of Global Extent and Geographical Patterns of Agroforestry*. ICRAF Working Paper 89. World Agroforestry Centre.

Annexes

Table 2.5 Major data sources consulted for system characterization

Item

Total, urban and rural human population

- FAOSTAT – for agric, rural, urban and females employed in agriculture
www.fao.org/faostat/en/#data/OA
- FAO/IIASA GAEZ ver 3.0 <http://gaez.fao.org/Main.html> and
<http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/>
- Harvest Choice Population <https://harvestchoice.org/products/data/4>
- CIESIN <http://sedac.ciesin.columbia.edu/data/collection/gpw-v4>
- AfriPop www.afripop.org/ and https://worldmap.harvard.edu/data/geonode:AfriPop1km_QCe
- UN Population Division World Population Prospects 2011 and World Urban Prospects 2014
www.un.org/en/development/desa/population/publications/pdf/trends/WPP2010/WPP2010_Volume-I_Comprehensive-Tables.pdf
- Projections for 2015 for individual farming systems were based on linear regression using data points from 2000, 2005, 2010 and 2014

Agricultural population

- Sub-Saharan Africa only
FAOSTAT
www.fao.org/faostat/en/#data/OA
Harvest Choice Population <https://harvestchoice.org/products/data/4>
AfriPop www.afripop.org/ and https://worldmap.harvard.edu/data/geonode:AfriPop1km_QCe
- For North Africa (NA), AfriPop 2010 was used as spatial footprint with agricultural population estimated from rural population with the following coefficients: 0.9 for NA pastoral and arid pastoral and oasis farming systems (low population density), 0.85 for NA highland mixed, rainfed mixed and dryland mixed farming systems (medium population density) and 0.8 for NA large-scale irrigated farming systems (high population density). High population density areas have relatively greater size and prevalence of rural towns. In contrast, low population areas have fewer rural towns and a higher proportion of agricultural population

Agricultural population density

- Agricultural population divided by total and cultivated area
Source: same as above

Undernourished people

- Centre for World Food Studies, Vrije University, Amsterdam
<https://research.vu.nl/en/publications/africa-in-maps-data-repository-of-the-food-economy-of-sub-saharan>

Extreme poverty – SSA only

- Harvest Choice
<https://harvestchoice.org/maps/sub-national-poverty-and-extreme-poverty-prevalence>
https://harvestchoice.org/data/tpov_pt125
https://harvestchoice.org/data/tpov_pd200
- Spatial data on poverty incidence in North African systems were not available and so administrative data and other estimates were referred to in the characterization of the farming systems

Total area, land area and water area

- Harvest Choice
<https://harvestchoice.org/topics/land-cover-and-use>
- FAO/IIASA GAEZ ver 3.0
<http://gaez.fao.org/Main.html>
<http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/>

(continued)

Table 2.5 (continued)

Item

Land use and land cover

- FAO Global land cover www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036355/
-

Cultivated area, crop land and pasture land

- FAO/IIASA GAEZ ver 3.0 <http://gaez.fao.org/Main.html>
<http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/>
 - Harvest Choice
<https://harvestchoice.org/topics/land-cover-and-use>
 - Ramankutty
www.ramankuttylab.com/data.html <https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2007GB002952>
www.earthstat.org/data-download/
-

Irrigated area and area equipped for irrigation

- FAO
Global Map of Irrigation Areas – Version 5
www.fao.org:80/geonetwork?uuid=f79213a0-88fd-11da-a88f-000d939bc5d8
Percentage of area equipped for irrigation
www.fao.org:80/geonetwork?uuid=a6fe7f5b-b887-452b-922a-668b7771b450
Occurrence of irrigated areas (FGGD)
www.fao.org:80/geonetwork?uuid=641e8b80-7592-11db-b9b2-000d939bc5d8
 - Harvest Choice
www.harvestchoice.org/maps/irrigated-cropland-area-ha
<https://harvestchoice.org/topics/land-cover-and-use>
-

Livestock population

- FAO
Livestock density
www.fao.org/ag/againfo/resources/en/glw/GLW_dens.html
Gridded livestock of the world 2007 <http://www.fao.org/ag/againfo/resources/en/glw/>
FAO/IIASA GAEZ version 3.0 <http://gaez.fao.org/Main.html>
<http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/>
FAOSTAT
www.fao.org/faostat/en/#data/QL
 - Harvest Choice
https://harvestchoice.org/data/ad05_lu
 - Tropical Livestock Units (TLU) are livestock numbers converted to a common unit.
Conversion factors are: cattle = 0.7, sheep = 0.1, goat = 0.1, pig = 0.2, chicken = 0.01. Factors taken mostly from www.lrrd.org/lrrd18/8/chil18117.htm, except for cattle. See also http://en.wikipedia.org/wiki/Livestock_grazing_comparison
-

Standard farm and herd size (cultivated area/household; TLU/household)

- Farm size: cultivated area divided by number of households (agricultural population divided by mean household size of 5.5)
 - Herd size: livestock population divided by number of households (agricultural population divided by 5.5)
 - Source: same as above
-

Major agroecological zone

- FAO/IIASA GAEZ version 3.0 <http://gaez.fao.org/Main.html>
- <http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/>
- Harvest Choice
- <https://harvestchoice.org/maps/aez-16-class>

- IFPRI
- <https://dataverse.harvard.edu/dataset.xhtml?persistentId=hdl:1902.1/22616>
- See also www.fao.org/docrep/W2962E/w2962e-03.htm

Length of growing period (LGP)

- FAO/IIASA GAEZ ver 3.0
- <http://gaez.fao.org/Main.html>
- <http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/>
- Harvest Choice
- https://harvestchoice.org/data/lgp_avg
- For more recent data see also <http://harvestchoice.org/labs/measuring-growing-seasons>
- See also www.fao.org/nr/climpag/cropfor/lgp_en.asp
- University of Twente – Anton Vrieling
- www.mdpi.com/2072-4292/5/2/982
- Average LGP is the average length of growing period tied to pixels where a given farming system occurs
- Core range refers to the boundaries of contiguous 30-day LGP intervals where at least two-thirds of the farming system occurs

Access to services

Author estimates of general access to services in the farming system were based on market access and quality, and other services such as diversity and quality of public and private service provision such as mobile phone coverage, market information availability, extension and veterinary services, availability of finance

Sources consulted:

- Sub-Saharan Africa – Harvest Choice distance to 20, 50, 100, 250 and 500k (population) market
- <https://harvestchoice.org/labs/travel-time-major-market-cities>
- Continental Africa – distance to 50k market
- Joint Research Centre – Global Accessibility map
- <http://forobs.jrc.ec.europa.eu/products/gam/download.php>
- Average distance presented in Table 2.2 is the average travel time to a town of 50k inhabitants tied to pixels where a given farming system occurs
- Core range refers to the boundaries of travel time intervals (0; 0–1; 1–2; 2–4; 4–6; 6–10; > 10) where at least two-thirds of the farming system occurs

Trends in biomass productivity

- FAO and ISRIC – World Soil Information, Wageningen Global change in Net Primary Productivity (1981–2003)
- www.fao.org/geonetwork/srv/en/metadata.show?id=37049&currTab=simple

Trees on farm

- ICRAF: Analysis of Global Extent and Geographical Patterns of Agroforestry (Zomer et al. 2009)
- www.worldagroforestry.org/downloads/publications/PDFs/WP16263.PDF

Elevation

- Sub-Saharan Africa
- Harvest Choice
- <https://harvestchoice.org/maps/elevation-meters>
- Continental Africa
- NASA Shuttle Radar Topography Mission SRTM
- www2.jpl.nasa.gov/srtm/

Yield gaps

- FAO/IIASA GAEZ ver 3.0
 - <http://gaez.fao.org/Main.html> and
 - <http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/>
-

Table 2.6 Selected major supporting documents, administrative statistics and assessment reports

Agency	Main administrative statistics, supporting documents
African	Adeleke Salami, Abdul B. Kamara and Zuzana Brixiova 2010. African Development Bank. Smallholder agriculture in East Africa: Trends, constraints and opportunities
	AfDB. 2014. African Economic Outlook 2014 Global Value Chains and Africa's Industrialisation
	African Union Commission 2017 Inaugural Biennial Review Report of the African Union Commission on the Implementation of the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods to the January 2018 Assembly
	AGRA. 2016. Africa Agriculture Status Report. Progress towards agricultural transformation in Africa
	AGRA. 2017. Africa Agriculture Status Report: The business of smallholder agriculture in sub-Saharan Africa (Issue 5). Nairobi, Kenya: Alliance for a Green Revolution in Africa (AGRA)
	AU. Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods
	FARA. 2013. Summary of plenary recommendations, 5th African Science Week, African agricultural innovation in a changing global environment
	FARA. 2014. Science agenda for agriculture in Africa. 'Connecting science' to transform agriculture in Africa. Forum for Agricultural Research in Africa. Accra, Ghana
	FARA. 2015. High-level conference on feeding Africa: An action plan for African agriculture transformation
	Montpellier Panel Report. 2013. Sustainable intensification: A new paradigm for African Agriculture
	Montpellier Panel Brief. 2013. Farmers on the climate frontline
	NEPAD-AU 2010. Highlighting the successes
	NEPAD-AU. 2013. The CAADP results framework (2015–2025). Introducing the comprehensive Africa Agriculture Development Programme (CAADP) NEPAD-AU
	The Africa Progress Panel (APP). 2010. Raising agricultural productivity in Africa: Options for action, and the role of subsidies
	The Africa Progress Panel (APP). 2015. Africa Progress Report 2015. Power, people, planet: Seizing Africa's energy and climate opportunities
International	Brookings Institute. 2017. Foresight Africa. Top priorities for the continent in 2017. Director and Senior Fellow, Africa Growth Initiative, Global Economy and Development
	FAO. 1996. Agro-Ecological Zoning Guidelines, FAO Soils Bulletin 73, Soil Resources, Management and Conservation Service, FAO Land and Water Division, Rome, Italy
	FAO. 2015. Regional overview of food insecurity in Africa
	FAO. 2015. The state of food and agriculture 2010–2011
	FAO. 2017. Regional overview of food security and nutrition in Africa 2017. The food security and nutrition–conflict nexus: building resilience for food security, nutrition and peace. Accra
	FAO/HLPE. 2009. The special challenge of sub-Saharan Africa
	IFAD. 2010. Rural poverty report 2011. New realities, new challenges: New opportunities for tomorrow's generation.
	IFAD. 2012. IFAD's approach to small island state development

- IFAD. 2016. Rural Development Report 2016. Fostering inclusive rural transformation
- John Lynam, Nienke Beintema, Johannes Roseboom, Ousmane Badiane (eds). 2016. Agricultural research in Africa: Investing in future harvests. IFPRI.
- Kathleen Beegle, Luc Christiaensen, Andrew Dabalen, Isis Gaddis. 2016. Poverty in a rising Africa: Africa poverty report. Overview. World Bank
- Malabo Montpellier Panel. 2017. Nourished: How Africa can build a future free from hunger and malnutrition
- Namukolo Covic, Sheryl L. Hendriks (eds). 2015. ReSAKSS trends and outlook report 2015: Achieving a nutrition revolution for Africa – The road to healthier diets and optimal nutrition
- Samuel Benin, Alejandro Nin Pratt, Stanley Wood, Zhe Guo 2011. ReSAKSS annual trends and outlook report 2011: Trends and spatial patterns in agricultural productivity in Africa, 1961–2010
- UNDP. 2015. Africa Human Development Report (2015): United Nations Development Program
- UNECA. 2015. Assessing progress in Africa toward the Millenium Development Goals. MDG Report, Lessons learned in implementing the MDGs
- UNECA. 2015. Economic report on Africa
- WHO/FAO. 2003. Diet, nutrition and the prevention of chronic diseases. WHO Technical Report Series Report of a Joint WHO/FAO Expert Consultation
- World Bank and OECD. 2015. The Africa competitiveness report. World Economic Forum
- World Bank. 2009. Awakening Africa's sleeping giant: Prospects for commercial agriculture in the Guinea Savannah zone and beyond
- WWF. 2012. Africa's Ecological Footprint Report

Table 2.7 Experts consulted for system characterization and delineation in addition to chapter authors and selected list of spatial data reviewed

<i>Country</i>	<i>Experts consulted and maps and data used</i>
Regional	FEWS NET Livelihood zones http://fews.net/fews-data/335t
Angola	1. Food Security Brief, FEWS NET Angola Desk Review, 2012 http://fews.net/southern-africa/angola/food-security-brief/october-2012 ; 2. Contour Map of Average Rainfall, Rainfall National Irrigation Plan (PLANIRRIGA), progress report # 2. (2010)
Botswana	Key expert inputs to FS map by Thabo Feribe; Alfred Lefaphane 1. Annual rainfall map, 1971–2000; 2. Harvest Choice spatial maps of crop production; LGP
Egypt (Nile River)	Key expert inputs to FS map by Ahmed Eltigani Sidahmed
Ethiopia	SIMLESA maps of: 1. mega maize environments by altitudinal zones; 2. maize production; 3. legume production; 4. livestock population
Kenya	1. Crop suitability maps; 2. Agroecological zones map provided by George Mburathi; 3. GAEZ / FAO LGP (based on 1961–1990 records); 4. Remote sensing LGP from Anton Vrieling; 5. FAOSTAT data on national crop areas; 6. Harvest Choice maize and coffee-banana areas

(continued)

Table 2.7 (continued)

Country	Experts consulted and maps and data used
Madagascar	Key expert inputs to FS map by Volatsara Rahetlah, FIFAMANOR; Tahina Raharison, GSDM, Eric Penot, Paolo Salgado, Pascal Danthu, and Eric Enjalric, CIRAD. 1. 2012 FEWS NET Madagascar Desk review including 2010 WFP Map of livelihood zones; 2. 2013 FEWS NET Madagascar Livelihood Zone Map; Elevation, LGP; 3. Harvest Choice maps for crops and livestock
Mali	1. Main agroecological units map of Mali
Mozambique	Key expert inputs to FS map by Joe DeVries, AGRA; Domingos Dias, IIAM 1. Food crop production per region, World Bank 2006; 2. Poverty, World Bank 2005; 3. Rainfall distribution, IFPRI 2011; 4. Land with intensification potential National Institute of Agronomic Research (NIAR) 2002; 5. Map of agroclimatic regions and research stations, NIAR 2002
Namibia	Key expert inputs to FS map by Bertus Kruger, AGRA, Windhoek 1. Farming Systems in Namibia, John Mendelsohn and others, 2006, RAISON, Windhoek
Nigeria	Key expert inputs to FS map by Tunrayo Alabi, IITA 1. Mean harvested yam area (2006–2009) from Ministry of Agriculture; 2. Mean yam production (2006–2009) from Ministry of Agriculture
Republic of South Africa	Key expert inputs to FS map by: Archer van Garderen, CSIR Natural Resources & the Environment, Pretoria and Daleen Lötter, CSIR Natural Resources & the Environment, Stellenbosch; Roland Schulze, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu Natal; Anneliza Collett, Land Use and Soil Management Directorate 1. Department of Agriculture, Forestry and Fisheries; Undated Agricultural Enterprises of South Africa Map, Department of Agriculture: Western Cape, Elsenburg, South Africa; 2. Updated national land cover map in Updating National Land Cover, SANBI (South African National Biodiversity Institute), Pretoria, dated 13/10/2009 http://bgis.sanbi.org/landcover/project.asp ; 3. Area (km ²) Per Quinary Catchment Production Forest Plantations (Eucalyptus, Pinus, Acacia Species) from National Land Cover (2000); 4. Area (km ²) Per Quinary Catchment Sugarcane from National Land Cover (2000); 5. Field Crop Boundaries, 2011, Department of Agriculture, Forestry and Fisheries (DAFF)
Tanzania	FEWS NET: Preliminary Rural Livelihood Zoning Tanzania, 2008. A Special report by the Famine Early Warning System Network (FEWS NET)
Uganda	1. Main farming systems map of Uganda, source: www.fao.org/ag/AGP/AGPC/doc/Counprof/uganda/uganda.htm#3.%20CLIMATE%20AND%20AGROECOLOGICAL ; 2. Livestock production systems in Uganda, source: Ministry of Agriculture, Animal Industry and Fisheries, Uganda; Uganda Bureau of Statistics; Food and Agriculture Organization of the United Nations; International Livestock Research Institute; and World Resources Institute, 2010, <i>Mapping a Better Future: Spatial Analysis and Pro-Poor Livestock Strategies in Uganda</i> . Washington, DC and Kampala: World Resources Institute. 3. Poverty rate: percentage of subcounty population below the poverty line, 2005 source: UBOS and ILRI, 2008; 4. Poverty density by rural subcounty: Number of people below the poverty line per square kilometre, 2005
Zambia	Key expert inputs to FS map by Moses Siambi

Part II

Analyses of farming systems

Taylor & Francis

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3 Maize mixed farming system

An engine for rural growth and poverty reduction

*Malcolm Blackie, John Dixon, Maxwell Mudhara,
Joseph Rusike, Sieglinde Snapp and Mulugetta Mekuria*

Key messages

- The maize mixed farming system in eastern, central and southern Africa is the food basket of the region, with good natural resources and an agricultural population of over 100 million with an average holding of 2.1 ha. This system integrates trees, livestock, and cash and food crops. Off-farm income is significant.
- The system is rapidly changing, driven by increases in population and urbanisation, gender roles, markets, information availability and climate change. Long-term agricultural growth prospects for transformational development are promising, with opportunities for diversification to horticulture and dairy, for crop-livestock integration and for agricultural intensification based around enhanced legume systems.
- Pathways to better food and nutrition security and broad-based inclusive sustainable development can be accelerated by greater investment in improved varieties and services, improved farm and value chain management, rural innovation and entrepreneurship, effective local institutions and enhanced enabling policies.

Summary

The maize mixed farming system is found largely in the sub-humid agroecological zone of eastern, central and southern Africa, with a crop growing season of around six months. It has a greater agricultural population, around 107 million in 2015, and more extreme poverty than other farming systems in Africa. It is the food basket as well as the driver of rural economic growth in the region. Many smallholders supplement dietary energy from maize with cassava and other root crops. Farm households are characterized by ageing farmers and an increasing role of women. Dietary protein derives from animal and fish products, and a variety of legumes grown as intercropped or in rotation with maize. Market access is reasonable for many areas. Cash crops include coffee, tobacco, cotton, groundnuts, vegetables and livestock products. Large and small ruminants are integral to the system, often grazed communally. Livestock and poultry augment household cash income and nutrition. Most smallholders earn substantial off-farm income and are net purchasers of food grains, often selling staples at harvest time to meet immediate household cash needs.

Cultivation is typically with hand hoes or animal draught, but with increasing use of machinery. The productivity of crops and livestock are limited by poor management as well as biotic and abiotic constraints. There are signs of serious fertility decline and evidence of increasing soil acidity where there has been prolonged use of inorganic fertilizers without manures or crop residues. Farmers are struggling to adapt to increased climatic variability. Over the medium to long term, the projected increase in temperatures and decline in precipitation associated with climate change are expected to reduce the potential yields of maize and other crops substantially, especially in southern Africa.

Widespread adoption of sustainable intensification and diversification requires improvement to input and output value chains, including better access to finance, knowledge, seed, fertilizers and pesticides, and produce marketing. Producer incentives for adopting new technologies and increasing productivity can control food prices and improve access to staple food for poor consumers, both urban and rural. Improved natural resource management is essential to ensure environmental sustainability and productivity in the future. Increased investments in agricultural research and rural infrastructure are critical. Interest is growing in targeting support programs to specific aspects of the maize mixed farming system, such as improved soil fertility, diversification, resilience or human nutrition. Public policies can create incentives for business investments in transport, storage and processing.

Overall, the potential for long-term improvement in food and nutrition security and reduced poverty is promising. The relative abundance of natural resources in the region provides the basis for pro-poor sustainable agricultural development if appropriate incentives are created through supportive national policies, reorientation of institutions, investment in innovation systems and provision of infrastructure, information and agricultural services. Broad-based inclusive agricultural growth with reliable access to services and inputs in poorer sections of the farming system will accelerate increases in small farm income.

Introduction

Maize was introduced into southern and eastern Africa from Latin America by the early Portuguese explorers in the 16th century (as were other important components of this system such as *Phaseolus* beans and groundnuts). Maize gradually spread north from the Cape and replaced the more labour-intensive small food grains (pearl millet and sorghum) and, initially, cassava. Maize became the main food staple for eastern and southern Africa early in the 20th century. In the southern parts of the region, maize-based farming was encouraged by the demand for food by the expanding mining industry.

The population density in eastern and southern Africa was low until the mid-20th century, in no small part as an outcome of the slave trade which devastated large areas. In this relatively land abundant era, labour was a major constraint; the seasonality of rainfed production means labour constraints persist today. Land preparation by hand hoe has a long tradition, due to limited draught power in some areas. Cattle, the main source of animal draught, are susceptible to severe diseases such as trypanosomiasis. Theft and scarcity of grazing also limit access to animal draught. There is evidence of farmers turning to mechanization. Most farm households engage in small-scale business activities, notably trading.

In the system, there are significant areas of sorghum, and food grains are complemented by root crops, especially cassava, legumes, notably beans, and horticulture. Cash crops include coffee, tobacco, cotton, groundnuts and sunflower. Cattle, sheep and goats are

common through the system, but per capita ownership of cattle is falling. Off-farm work (many young men work in mines and other industries) is prevalent across the system. The expansion of market-based institutions has stimulated diversification towards higher value crop and livestock activities – although national policies which focus on increased maize production are a core strategy for achieving food security and reducing poverty in the region (Homann-Kee Tui et al. 2012).

Overview of the farming system and subsystems

The maize mixed farming system and its nine subsystems extend over about 361 million ha of eastern and southern Africa (Figure 3.1), of which some 40 million ha are cultivated and only 1.9 million are irrigated (Table 3.1). Of the total population of 180 million in 2015, including cities and towns, some 107 million are agricultural (expanding at 2.7 per cent annually) – more than any of the other farming systems in Africa. At an average of 5.5 persons across all types of farm households, this system has about 19.5 million farm households. An estimated 56 per cent of the farm population lives in extreme poverty (using the standard definition of daily consumption of less than US\$ 1.90 per capita) – greater number than any other African farming system. Despite the prevalence of poverty and the increasing average age of farmers, the farming system serves as the food basket as well as the driver of agricultural growth in eastern and southern Africa.

Geographically, the system extends across plateau and highland areas at altitudes of approximately 800 to 1500 metres, from Ethiopia, Kenya and Tanzania to Zambia,

Figure 3.1 The maize mixed farming system and subsystems.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Table 3.1 Basic system data (2015): maize mixed farming system

<i>Item</i>	<i>Estimates</i>
Total human population (million)	181
Agricultural population (million)	107
Total system area (million ha)	361
Cultivated area (million ha; % of total area)	40; 11
Irrigated area (million ha; % of cultivated area)	1.9; 5
Total livestock population (million TLU)	36
Main agroecological zone	Tropical subhumid
Length of growing season (average, days; core range, days)	196; 150–240
Access to services (low/medium/high)	Medium
Time to market (average, hours; core range, hours)	8.3; 2–10+
Agric population density (persons/total area; persons/cultivated area)	0.3; 2.7
Livestock density (TLU/total area; TLU/cultivated area)	0.1; 0.9
Standard farm and herd size (cultivated area/household; TLU/household)	2.1; 1.9
Extreme poverty (% of rural population)	56

Source: Refer to Table 2.4.

Malawi, Zimbabwe, South Africa, Swaziland and Lesotho with low altitude extensions into central Africa (including the Democratic Republic of Congo (DRC)) and Madagascar. Originally most of the area was heavily forested, but increased population pressure led farmers to push the agricultural margin into the forests, and indigenous forests have also been thinned or clear cut for timber or to create commercial forests.

The maize mixed farming system has two key characteristics: a medium to high potential agroecological potential and, second, a medium level of access to markets. The farming system is found largely in the tropical warm sub-humid climatic zone with an average growing season length of 196 days (between six and seven months), termed length of growing period (LGP). The core of the system falls in the zone within 150–240 LGP, with climate varying from dry sub-humid to moist sub-humid. The length of growing season, and hence the potential yield of crops, varies substantially across the system and between years, largely as a consequence of the *El Nino* weather patterns. Within the season, crop growth is particularly sensitive to drought at establishment, flowering and grain-filling stages. The most typical areas of the system have monomodal rainfall, but some areas close to the equator (Kenya, Uganda, and some of Tanzania) have a bimodal rainy season with two growing seasons.

Although dominated by the staple maize crop, the system is typically a diversified mixed system incorporating significant numbers of livestock (36 million tropical livestock units (TLU) in total) and areas of root crops, pulses, oil seeds and sorghum (total crop area is 40 million ha). Beans, other legumes and cassava are often planted as intercrops. Cassava is particularly common in three different contexts: areas with frequent droughts such as in southern Africa; areas where cassava has been commercialized such as Mozambique; and areas where cassava was traditional but farmers are adopting maize, such as in central Africa. Both local and improved maize varieties are grown, although the taste and processing characteristics of the local varieties are sometimes preferred. Sorghum is more drought tolerant than even the recent drought and stress tolerant maize varieties but is grown on less than 10 per cent of the cropped area in the farming system, increasingly for home-brewed beer or sale to commercial breweries. Groundnuts, beans and cowpeas,

with expanding areas of pigeon pea, chickpeas and soybeans, are important legumes in the system (Figure 3.2) and are planted on more than 15 per cent of the cropped area. Legumes are an important source of dietary protein and contribute to soil health and livestock fodder, as well as an expanding role as a source of cash. Traditional cash crops include coffee, tobacco and cotton. As in other parts of Africa, livestock and many food crops are increasingly marketed by smallholders.

The maize mixed farming system contains only 1.9 million ha of irrigation, mostly scattered and small scale with the notable exception of Madagascar, which has a significant area of irrigated rice. Substantial numbers of smallholders have access to small areas of potentially irrigable land in the shallow valley bottoms, sometimes known as dambos or vleis in southern Africa. Farmers establish gardens on these dambos for high value crops, grown on residual moisture or supplemental irrigation, often pumped from shallow wells or surface sources. Crops include green leafy and other vegetable crops such as tomatoes, as well as winter maize (an important market crop as ‘green maize’) for both the market and home consumption. These wide valley bottom areas are also of considerable importance for grazing, particularly during the dry season.

Livestock production, supported in most areas by functioning local grazing institutions, is a major income-generating activity and, in some areas, has the potential for more consistent returns on investment than crops (Ryan and Spencer 2001). Per capita ownership has been dwindling since the turn of the century. Small ruminant and poultry numbers are steadily increasing in most countries (Homann-Kee Tui et al. 2012).

Figure 3.2 A field day in Kande, Central Malawi, with a farmer evaluating agronomic benefits of rotation of soybean with maize.

Source: Sieg Snapp.

One of the striking aspects of the system is the growing access to labour markets. Thus, off-farm income is a critical source of livelihoods, especially for households with smaller farms – and in drought years. As young males migrate in search of farm work, farm women play expanding roles in farm management and marketing. Sometimes women do undertake local off-farm work, which unfortunately compromises the productivity of their own fields. The expansion of rural road networks during the past few decades has given most farm households moderate or good access to farm input and produce markets, thereby opening up new income earning opportunities. Smallholder household income is significantly augmented by off-farm employment, trading and small businesses. Off-farm employment includes work (often for food) on nearby farms, as well as seasonal migration to nearby towns and cities, or other countries.

Population density is 0.3 persons per ha, equivalent to 2.7 persons per cultivated ha. An average farm household cultivates 2.1 ha and manages 1.7 TLU of mixed livestock. The variation is substantial across the system and within communities. Overall, the system has medium level access to services, with an average time of 8.3 hours to large market towns with populations of 50,000 or more. The core hunger season typically occurs in the late dry season and early wet season after stored food grain runs short and before the next harvest. Because cassava roots can remain in the ground, they are often harvested during this period. Some crops provide food from early in the growing season, for instance green maize (immature maize cobs). Nutrition is supplemented cassava leaves in the dry season and legume leaves in the wet season, as well as forest products, milk products and poultry. Naturally, the bimodal rainfall systems in the eastern African part of the system tend to generate more stable household food and nutrition security.

Smallholders occupy more than 90 per cent of cultivated land. Larger and wealthier smallholders often cultivate more cash crops and manage more livestock (Table 3.2). Of the typical cultivated area of a smallholding (2.1 ha), half is planted to cereals and 0.35 ha to cassava, sweet potatoes and other roots. Legumes and groundnuts account for 0.37 ha, and cash crops only 0.14 ha. The profile of typical maize mixed system smallholders is outlined in Box 3.1 (but there is considerable variation).

As only 11 per cent of the farming system land is cultivated, most farm households access significant common grazing land. Livestock holdings average 2.3 cattle, including

Table 3.2 Average farm household enterprise pattern: maize mixed farming system

<i>Percent land in crops (%)</i>		<i>Selected farm household characteristics</i>	
Maize	35	Family size (persons)	5.5
Sorghum, millet	8	Cultivated land (ha)	2.1
Rice	5	Livestock (TLU)	1.9
Wheat, barley, other cereals	3	Cattle (no)	2.3
Cassava, sweet potato, other roots	19	Small ruminants (no)	2.6
Bananas	2	Poultry (no)	13
Pulses	14	Off-farm income	Often 40–60% of total household income
Groundnuts	6		
Cotton	3		
Vegetables	2		
Coffee, tea	3		

Source: FAOSTAT.

dairy cows, 2.6 small ruminants and around a dozen poultry. Most large and small ruminants use the common grazing and water points, although in the dairy sector numbers of staff fed animals are growing.

Box 3.1 Typical smallholder farm household profile

A typical smallholder five-six person family farm would have a cropped area of 2 ha of which 0.5–1.0 ha would be planted to maize. The equivalent of about half the maize area will be devoted to other cereals such as sorghum, millet, rice or wheat. Maize and other cereals account for 80 per cent of total food production – further plantings include pulses, roots and tubers, oilseeds and vegetables. Where market access is reasonable, small areas may be allocated to cash crops such as cotton, tobacco and coffee. The family owns two or three small ruminants or cattle, generally communally grazed, and uses its oxen to plough the land (in some areas, where cattle are scarce, cows are used, but they lack the strength and their fertility is compromised). Typical yields are low – around 1.2 t/ha for maize and 500 kg/ha for beans or other pulses. The household would be food self-sufficient in average to good years and deficient during extreme weather years (poor rainfall, illness or other external events). One son works in the capital and sends occasional remittances which are used to pay for school and medical fees and clothes. Home-grown maize is the main source of subsistence. Cash is obtained either from off-farm activities, local trading, or from the sale of agricultural products such as maize, cotton, coffee and milk. Although household income would be above the poverty line in average seasons, often sales are made at harvest when returns are lowest, and cash is a major constraint on the purchase of improved inputs.

In this system about 56 per cent of the agricultural population is extremely poor with a daily per capita consumption of less than US\$1.90; about half manage small- to medium-sized farms with modest farm incomes, and only a few could be termed large or rich farmers.

Changes in the socioecological economic environments in Africa since the turn of the century have led to changes in the extent and characteristics of the maize mixed system. For example, compared with Dixon et al. (2001), increasing commercialization has led to some areas of the maize system being transferred to the market-oriented highland perennial farming system. With the continued adoption of maize in previously extensive systems, a large swathe of central Africa has been reclassified from mixed cereal and root crops to the maize mixed system. There has been a substantial increase in diversification since 2000, especially into dairy and horticulture. These changes are driven by an increase in the availability of agricultural production, market and policy information and wider choices in production and marketing management.

Subsystems

For ease of use by policy makers, the maize mixed farming system can be subdivided into nine distinct subsystems grouped by countries with recognizably different production and livelihood patterns and institutional and policy environments. Both agroecology (altitude, rainfall, length of growing season) and market access determine the subsystems, as shown in Table 3.3.

Table 3.3 Key characteristics of the subsystems

<i>Subsystem name</i>	<i>Market access (hours from city)</i>	<i>LGP (days); Altitude (m)</i>	<i>Total area; Cultivated area; Agricultural population; Cattle population</i>	<i>Principal subsystem features</i>
Ethiopian maize- livestock	Low (11.4 h)	Medium (198 d) Medium-high altitude (1244 m)	17.9 mha 2.8 mha 11.5 m 8.5 m	Medium intensity crop-livestock system, small farm size (1.3 ha), monomodal (single crop season), about four cattle per household, livelihoods from maize, cattle, teff, oil seeds and legumes including haricot beans and sesame as cash crops, some sorghum, off-farm income.
Kenyan- Ugandan hoe-tractor maize	Medium (7.0 h)	Long (253 d) Medium altitude (961 m)	34.6 mha 6.5 mha 29.1 m 12.3 m	Medium intensity, bimodal (two crop seasons), small farm size (1.2 ha), hoe/tractor power, some external inputs, relatively good access to seed, livelihoods from hybrid maize, banana, cotton, vegetables, off-farm income (note: includes some districts of northern Tanzania).
Tanzanian semi- mechanized maize	Medium (7.3 h)	Medium-long (211 d) Low-medium altitude (745 m)	37.9 mha 5.6 mha 11.3 m 3.9 m	Central and southern parts medium intensity, monomodal (single crop season), medium farm size (2.7 ha), partially mechanized, livelihoods from hybrid maize, diversified (beans, pigeon pea, sorghum, cotton, vegetables), off-farm income.
Malawian market- linked maize	High (5.0 h)	Medium (183 d) Medium altitude (974 m)	8.8 mha 3.8 mha 11.1 m .04 m	Monomodal (single crop season), densely populated, small farm size (1.9 ha), few cattle, livelihoods from maize, legumes, oil crops, cash crops, significant seed and fertilizer use, off-farm income.

Central African scattered maize-root crop	Low (11.7 h)	Medium (199 d) Medium altitude (1110 m)	86.1 mha 5.0 mha 9.2 m 0.2 m	Monomodal. Medium-large small farm size (3 ha), low-medium fertility, low yielding extensive food crop and subsistence oriented including cassava (few cash crops), low external input use, few livestock, non-tree forest products and mining income.
Mozambican extensive maize	Medium-high (6.6 h)	Medium (201 d) Low altitude (431 m)	47.6 mha 4.3 mha 13.0 m 0.25 m	Small-medium farm size (1.8 ha), low yielding food crops and significant drought risk, commercialization of cassava (for starch) and sorghum (for beer), off-farm income.
Southern African dualistic maize	High (3.5 h)	Short (129 d) Medium-high altitude (1227 m)	51.6 mha 7.4 mha 5.8 m 8.2 m	Dualistic (large commercial/small subsistence), therefore average farm size of 7 ha, intensive with high yields, off-farm income for smallholders, cash crops on large farms, livestock for all farms.
Zambian medium population density maize	Medium-low (10.5 h)	Medium-short (178 d) Medium-high altitude (1147 m)	61.4 mha 3.6 mha 7.5 m 1.6 m	Monomodal (single crop season) medium-large small farm size (2.6 ha), low external input use, mixed hoe, animal draught and tractor power, livelihoods from maize, root crops, pulses, livestock and off-farm income.
Madagascan maize-rice	High (5.0 h)	Long (310 d) Medium altitude (999 m)	15.6 mha 1.1 mha 8.3 m 2.5 m	Small farm size (0.7 ha), significant irrigation, diverse cropping system including upland rice and tree crops, livestock.

Note: the ratings of low, medium and high for subsystems are relative to the average for the whole maize mixed farming system.

The northern maize-livestock subsystem in Ethiopia is a mixed system with a medium length crop growing season and a monomodal rainfall pattern. Cattle and trees play important roles in power, energy provision, resilience and diversification of livelihoods. Population density is high and farm size is small. There is a significant area of teff (*Eragrostis abyssinnica*), the unique national small-grained traditional cereal, along with cash commodities: haricot beans, sesame and livestock. Animals provide draught power as well as manure. Off-farm income is a major source of livelihoods. Although market access is poor, significantly constrained by poor secondary roads, the extension service is one of the best in Africa, and technical information, improved seeds and fertilizer are available to many farmers. The area of maize has been expanding at about 1 per cent annually since 2000, whereas maize yields have been increasing at around 5 per cent per year. Yields of groundnuts, cassava and other crops are trending up.

The hoe/tractor subsystem of Kenya, Uganda and northern Tanzania is the most populous subsystem. With an average altitude but a bimodal rainfall pattern which underlies a long crop growing season, the subsystem has medium access to markets but fewer cattle than the Ethiopian subsystem. Smallholder dairy is emerging as a remunerative activity in selected areas. Maize dominates the cropping pattern which has better-than-average diversity with significant areas of cash crops, notably coffee, tea, fruit and vegetables. There has been a relatively long tradition of access to improved seed, particularly OPV and hybrid maize, and fertilizer, which has led to recent increases in productivity. Markets strongly influence cropping patterns, particularly for tea and coffee.

The moist bimodal intensive subsystem with high population density is found in the hilly environments of Rwanda and Burundi. Farm sizes are small and land use intensity is higher. Services and market access are generally weak with poor development of rural businesses. Cropping systems are diversified, but livestock numbers are relatively low.

The central African scattered maize-root crop extensive subsystem, typified by DRC, is a marked contrast to the above subsystems. Land and water resources are plentiful but infrastructure, services and access to markets are weak and crop yields are low. Notwithstanding the recent expansion of commercial cassava production, maize production has grown rapidly and forest products play an important role. Other cash crops and livestock play modest roles.

The semi-mechanized subsystem in the central and southern parts of Tanzania are diversifying with medium market access, notably cotton, tobacco and the expanding market chains for pigeon pea exports. Farms are medium sized with livelihoods derived from hybrid maize, beans, pigeon pea, sorghum, cotton, vegetables and off-farm income.

The medium intensity subsystem of Malawi has far fewer livestock than other subsystems, which has implications for livelihood portfolios, risk management and the management of biomass and nutrient flows at the farm and landscape levels. The monomodal rainfall of Malawi limits the diversification options available compared with comparable bimodal areas. Legumes, especially groundnuts, and cash crops are important.

The medium population density subsystem in Zambia has monomodal rainfall, farm size is medium-large and external input use is low. Cultivation depends on hoe, animal draught and tractor power. Livelihoods are mixed, from maize, root crops, pulses, livestock and off-farm income.

Madagascar (upland rice and irrigated subsystem) has a major secondary cereal, upland rice, to complement the maize crop, partly because of major areas of irrigation. Farm sizes are small yet farmers can take advantage of employment opportunities arising in neighbouring farming systems and cities.

Mozambique has a relatively extensive system, with medium farm sizes and several other food grain crops including sorghum with medium-high market access, illustrated by the significant commercialization of cassava and sorghum. Nevertheless, off-farm income from migration to South Africa is a major source of livelihoods.

South Africa and Zimbabwe show dualistic land tenure arrangements: a mix of smallholder and large commercial farms. Smallholders have notable off-farm income, both in agriculture and industry. Land tenure changes mean large farms may decline in coming years.

Broad development needs vary across the subsystems. For policy makers, it is worth noting the differences in the crop-cattle ratios across the overall system. Livestock availability (and access to draught power) varies widely. Market development is very poor in some subsystems.

Trends and drivers of change across the system

There are seven major drivers of change of the system: population, natural resources, energy, knowledge, technology, markets and policies. In broad terms, the cultivated area will increase from 40 mha to approximately 49 mha by 2030 (authors) with higher rates of expansion in several medium-low population density subsystems, notably the subsystems of central Africa, Zambia and Mozambique. Land use and livelihood patterns will evolve substantially by 2030. As a past example using the period 1961–1999 in Kyamtwaru division, Bukoba district, Tanzania, the area of grassland declined by 40 per cent while cultivated fields increased in area by 225 per cent. The cultivation of maize and root crops in pure stands became more prevalent. Farmers reduced the cultivation of the traditional small food grains, sorghum and finger millet. Indigenous cattle numbers halved while dairy expanded (but concentrated in fewer households). Cattle-owning households decreased by 85 per cent. Increasing population density, changing land tenure, distribution and economic policies, and poor crop markets were the major drivers of the changes (Bajjukya et al. 2005).

Maize cropping will displace lower yielding and more labour-intensive traditional food crops. The proportion of smallholder farm households who are net purchasers of staple crops, typically selling produce at harvest time to bring in needed cash, will grow (Jayne et al. 2004). New market opportunities will emerge for smallholders with access to technologies and resources. The prevailing increases in rural populations will drive significant intensification and diversification.

Population, hunger and poverty

Increasing population density will continue to shape the system in the future. The traditional maize mixed system developed to optimize the use of family labour over the medium length growing season, originally by using shifting agriculture. Where family members find off-farm employment, labour shortages may occur. In recent times the land frontier has nearly closed in some subsystems, for example Rwanda or Malawi. Where there is little new employment outside agriculture, this accelerates the ongoing reduction of farm size (see discussion in the next subsection) and increases land fragmentation – constraining farm growth, intensification and diversification options for the next generation.

Except in a few densely populated areas with reliable access to irrigation (such as on the slopes of Mount Kilimanjaro or Madagascar), the farm size of smallholder hoe agriculture

Figure 3.3 Direct seeding of maize with animal drawn seeder, Kisilo village, Njombe district, Tanzania.
Source: Saidi Mkomwa.

was determined by the capacity of the household to cultivate and weed the cropland. With animal draught power, households can cultivate up to about two ha (Figure 3.3). Mechanical power, either small two wheel or larger tractors, enables farms to cultivate larger areas where land is available or consolidation possible. Mechanized land preparation is becoming an option for smallholders who can afford it, and mechanized land preparation is expected to become more widespread during the 2020s.

The rural population in east and southern Africa (which includes towns and service centres) has grown rapidly since 2000 – faster than in other regions of the world, even as the region is urbanizing rapidly. The farm population of 107 million in the maize mixed farming system confronts a massive challenge: their own food security as well as that of another 74 million living in cities within the area of the system. This excludes exports to other countries and to nearby lower potential areas. Urbanization is increasing the total demand on local food production and serves to encourage farms into higher value products.

The farming population is getting older, which may impede investment in farm resources and adoption of new technologies. As an increasing proportion of households are female-headed, new constraints related to land tenure and access to credit and other services emerge.

Human health and farm productivity are closely related. Even before the devastating effects of the AIDS pandemic, labour was often seriously short at critical periods of the

crop cycle such as planting and weeding. The start of the rains often brings diarrhoea and malaria. For women-headed households for whom family labour is particularly scarce, illness of a family member often results in late planting or weeding and low yields of food crops. To feed her family, she will need to work for nearby farmers, typically planting or weeding – a downward spiral creating much of the poverty in the system.

Hunger and poverty trends are causing widening socioeconomic differentiation. Poverty limits purchasing power and ability to acquire external inputs even where input markets are functioning, as well as access to credit. Hunger reduces labour productivity and limits the effectiveness of government educational and development programs. In some areas of high population density with limited external employment opportunities, the farming system is trending rapidly towards crisis, often exacerbated by the inaccessibility of productivity-enhancing modern inputs such as improved seed, fertilizer and agro-chemicals. Farm households move, most often to peri-urban slums (see Chapter 16 for an analysis of the urban and peri-urban farming system). Retrenchment of off-farm workers, coupled with policy reforms removing subsidies for food crop inputs and food grain prices, is a double blow to many of the poorest in the system.

Where off farm employment opportunities exist, population growth can augment the supply of labour in secondary and tertiary industries, and boost the demand for food. The increased demand, whether rural or urban, strengthens food grain and other markets and expands farmer opportunities. With rising incomes and shifting food preferences of consumers to include non-staples, smallholders can benefit from diversification to high value crops, livestock (including dairy) and fish.

Natural resources and climate

Both climate change and availability of natural resources are major determinants of farming and food systems. As an outcome of population pressure in the system, typical cultivated areas of smaller farms have fallen in some places to less than 0.5 ha (compared with the average farm size of 2.1 ha across the farming system). Such small farms operated under rainfed conditions with only moderate market access do not produce enough food or other livelihoods for households. Their livelihoods are commonly supplemented by off-farm earnings. Encroachment of cultivation into scarce grazing land will mean a reduction in cattle numbers in some high population density areas such as Malawi where cattle for draught power are almost totally absent.

Trends in farm size distribution indicate that population growth, urbanization and the changing composition of the economy will push towards smaller farm sizes¹ (Figure 3.4), and greater fragmentation of farms (Mallawaarachchi et al. 2014). In some areas informal arrangements to increase the managed farm area exist so that even without firm legal title to land the existence of conservation and investment incentives is possible (Bezabih et al. 2016).²

There are signs of serious fertility decline over much of the system. Key issues for farmers include the high cost of mineral fertilizer relative to the price of maize and other crops (at existing productivity levels), the difficulty of maintaining soil fertility, shortage of livestock to produce manure due to feed shortage, and the lack of oxen for farm power. Importantly, soil nutrient deficiencies mean that the crop can make effective use of only 10 to 15 per cent of total rainfall.

Climate change and the associated progressive increase in temperatures and decline in precipitation are expected to reduce maize and other crop yields substantially, especially

Figure 3.4 Average farm size trends in SIMLESA countries of eastern and southern Africa³.

Source: Data produced by Christopher Auricht in Mallawaarachchi et al. (2013, 2014).

in southern Africa (Thornton et al. 2010). The end date of the rainy season is more reliable than the start; there is evidence of onset of the rain becoming later thus reducing the growing season. Farmers struggle to manage their systems as climatic variability and extreme climatic events (droughts, for example) increase. They are forced into low-risk and sometimes lower yielding production patterns.

Energy

Energy is a critical input to agricultural intensification and also to value chain function essential for transformation of the system. Some traditional energy inputs, biomass, labour and animal power, are available in some parts of the system. A transition from biomass to modern renewables and fossil fuel-based traction and transport is expected. Fossil fuels and electricity availability is growing in the more accessible parts of the system. There are ambitious plans for expansion of grids in the 2020s. Solar, wind and other renewable are attracting increasing investments for the 2020s, which will facilitate intensified water pumping, production, processing and transport. There are likely to be major farming system changes as value chains develop for more extensive subsystems such as in central Africa.

Many maize mixed farms typically use slow, inefficient and physically demanding manual cultivation techniques (complemented with animal draught where available). These are particularly challenging for the elderly and women who remain on the farm, when the more able-bodied seek better paid employment elsewhere. Weeding is labour and energy intensive; labour can be reduced by technology (such as herbicides and animal draught – where accessible). Weeds and the pay-off to better weeding, increase with intensification, and with much diversification. Draught availability has been compromised in the southern parts of the system where the droughts of the 1990s, followed by Corridor

disease,⁴ decimated draught animal populations. The record of government-sponsored tractor schemes is poor. In the wealthier parts of the system, there is some growth in four- and two-wheel tractors for production, local transportation and water pumping.

While mechanization is progressively saving labour and human energy inputs to annual crop production, the gradual uptake of reduced tillage is beginning to reduce the labour requirements for crop production. Reduced tillage is generally associated with some additional energy inputs including fertilizer. Such improvements in production practices generally lead to increased energy use efficiency. Such promising technologies require further testing under local conditions (Andersson and Giller 2012; Giller et al. 2009) if they are to expand in future decades.

The intensification of livestock production is also increasing energy requirements. Dairy, small ruminant fattening operations, and semi-commercial poultry production will increase energy requirements in farming – for example, milk cooling, refrigeration and transport – especially in the subsystems with better market access in Kenya and South Africa.

Biomass is the principal source of domestic energy but is becoming increasingly scarce with the loss of forests. Tree production on the larger and better endowed farms is becoming more widespread, in part to enhance family fuelwood supplies.

Human and social capital

One of the most important drivers for development of the system will be widespread knowledge of innovations, markets and policies. The traditional separation of roles for food and cash crops between women and men has been breaking down in many areas as men have sought work outside the community. Women have been empowered by universal (male and female) education, market access, new technologies (mobile phone money transfers) and farming system innovations (crop-livestock integration, stall-fed dairy production). In Zambia, the growing roles of women in farm household decision making has been documented (van Koppen 2001).

Countries are planning for major increases in agricultural productivity, employment and profitability of the maize mixed farming system. But consideration of the human resources necessary to implement these plans is typically based on unrealistic and highly optimistic assumptions and generally overlooks aspects related to gender. Investment in human capital development overall has been constrained by weak support for universities. Public sector hiring freezes have eliminated an important avenue through which young graduates gain experience.

A deficit is emerging of young agriculturalists, especially women, gaining professional experience in agricultural services – a major challenge when the current generation of experienced African agriculturalists reaches retirement (Cabral and Scoones 2006). Transformation of the system needs better-informed and supported decision making by producers and value chain operators – service providers, aggregators, traders and processors – supported by service providers with interdisciplinary and systems competencies.

There is change. Not only are younger farmers better educated, but most farm households are better informed about labour, input and produce markets and available technologies. The improvement of rural communications, including radio, TV, sometimes internet and especially mobile phone connectivity will underpin a revolution in knowledge sharing to boost productivity and resilience of the system. Growth in the availability of innovation and market knowledge will be a major driver of change,

most especially in the low population density subsystems in Central Africa, Zambia and Mozambique. Along with ICT-based communications will come a variety of decision support tools which will improve management decisions of farm women and men and value chain operators.

Science and technology

Since 2000 the investment in market, agricultural services and policy research has expanded considerably, in line with the growing awareness of the complementarity between technology, market access and enabling policies. Smallholder choice among improved varieties and breeds and complementary production, processing and storage technologies has grown. However, despite the availability of yield-enhancing technologies in most countries of the system, food crop productivity increases have been modest and gaps between farm yields and attainable yields remain large.

The situation is improving. About 160 drought tolerant maize varieties have been released since 2006, and provided coverage of the total system by 2015. African seed companies are actively producing and marketing seed of these varieties to smallholders, and the commercial provision of seed will expand over coming decades. The new drought tolerant varieties have at least 30 to 40 per cent yield advantage over existing materials under severe stress, and similar yield advantage under optimal conditions (Shiferaw et al. 2011). Many new productive and abiotic/biotic stress resistant varieties are expected to be released during the 2020s, including nitrogen-efficient maize varieties. There has also been substantial progress in improved cassava, bean and pigeon pea varieties.

Despite the development of improved varieties for the maize mixed system, many food crop producers use farm-saved seed due to access issues. In one survey about 82 per cent of rural households identified maize seed supply as a major agricultural constraint (Langyintuo et al. 2010). Farmer and other civil society groups are now organizing farmer-based seed multiplication systems linked to farmer-based knowledge sharing of technical information. There are widespread exchanges of seeds among farmers in neighbouring areas and even countries. Donors and NGOs also distribute free kits, especially to the poorest farmers.

Researchers have also made great strides since 2000 in improved crop management to complement the genetic gains. Good crop management has underpinned the expansion of pigeon pea and the noteworthy development of the export industry. Substantial progress has been made across the maize mixed farming system on adapting conservation agriculture to the maize legume cropping system in a majority of the subsystems, from Ethiopia to Mozambique. Recent results from SIMLESA agronomic studies in Malawi and Mozambique confirmed the added benefits of conservation agriculture-based sustainable intensification practices evaluated on farmers' fields resulting in 30 to 60 per cent yield advantage, 40 per cent labour cost reduction and improved soil fertility (Nyagumbo et al. 2015).

Sustainable resource management research will target widespread land degradation and declining soil fertility with a view to landscape restoration, soil recapitalization and improved productivity. Farmer-managed natural regeneration of indigenous trees on maize croplands is being adopted in Malawi as a practical and low-cost response to these constraints. Lack of moisture can be alleviated by small-scale irrigation and water harvesting – fostered by participatory, applied research focused on integrated technologies blending indigenous and scientists' knowledge.

The combination of adapted technologies and market demand will increase diversification to incorporate dairy or other livestock into the maize mixed system. The development of small-scale dairy management systems in the Kenyan and Tanzanian subsystems has been impressive, and further adaptation can be expected as these systems expand into new areas. Such diversification generally creates a demand for research on forage species and management practices, as well as other crop-livestock integration technologies such as improved feeding systems for cross-bred dairy cattle and small ruminants.

The integration of perennials into the maize mixed farming system is expected to increase. Based on over two decades of intensive research, the incorporation of fertilizer/fodder trees into the maize mixed system is now being promoted as a means to enhance both fodder production and soil fertility under either full or reduced tillage (e.g. FAO 2010, 2011). These practices are currently being extended to hundreds of thousands of farmers in Malawi and Zambia (Akinnifesi et al. 2010; Garrity et al. 2010). Integrated soil, plant and landscape computer modelling has expanded massively and broadened to include livestock and trees, and ultimately household consumption and management decision making. While public sector investment in research declined in the years leading up to 2015, and there was little growth in private investment. As the system becomes more commercial and diversified, private sector investment will grow, and industry and farmer groups will invest in adaptive research on production and processing methods.

Trade and markets

While market access for most agricultural commodities has developed rapidly since 2000, albeit somewhat unevenly, scaling out technological innovations requires reliable and competitive input supply chains (including seed, fertilizers and pesticides) and knowledge dissemination accompanied by produce marketing. But developing an efficient input-output value chain is costly when demand for inputs is erratic and marketed output highly variable. Although the business environment for small- and medium-sized enterprises is improving in eastern and southern Africa, there are still significant constraints to effective rural value chain operation. These include private sector access to public technologies and know-how including germplasm, limited availability of experienced and qualified staff, lack of awareness/demand among farmers and lack of access to credit (for both agribusiness and farmers). Weak rural institutions for delivery of services and inadequate farmer organization contribute to poor capacity for remedying market imperfections in the supply of key inputs and marketing surplus produce. This affects seed companies, input suppliers and equipment distributors alike.

Technical change requires improved market access – both to stable output markets offering remunerative prices, and to input and finance markets to support the purchase of inputs, machinery or labour hire, or investment in equipment or infrastructure (Ebanyat et al. 2010).

Since 2000 the input/output price ratio for maize steadily deteriorated following trade reform and price liberalization. Following the removal of input subsidies, the dismantling of price supports, withdrawal of the state from grain purchasing and abolition of pan-territorial pricing, most smallholders struggled to adjust to rising input prices and declining maize grain prices. Alongside this, smallholder input supply, credit and marketing services collapsed and the private sector response was less than anticipated. As

governments withdrew from seed production, the private companies focused on hybrid maize. Smallholder access to good quality open-pollinated seed (OPVs) (not only of maize but of vegetables and other minor crops) has been a problem until small domestic seed companies in Uganda, Zimbabwe, Mozambique and Tanzania then began to produce and market OPVs.

In some countries, there is now a significant private sector seed industry. Langyintuo et al. (2010) estimate that around two-thirds of all seed sold through the formal sector is maize. In the late 2000s, there were nineteen registered maize seed companies in Angola, Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Uganda, Zambia and Zimbabwe. Today, a total of about eighty companies in the same nine countries produce and market 103,600 tons of seed, sufficient to cover 35 per cent of the maize area (Langyintuo et al. 2010). Given that the number of seed companies increased four-fold between 1997 and 2007, but the quantity of seed marketed barely doubled, this suggests that the seed production and deployment environment is less than favourable.

Langyintuo et al. (2010) exhaustively analysed the maize seed value chain and noted several critical bottlenecks which apply, in the main, to the seed systems of other improved crops. Establishing a seed production facility is expensive and capital is difficult to access. Thus the seed sector is largely monopolized by the large regional and multinational seed companies. The transfer of genetic materials between public and private sectors is inefficient. Rapid regional spillovers of varieties released in one country to similar agro-ecologies in different countries are compromised by a failure to implement harmonized regional seed laws and regulations. Over a third of seed companies surveyed considered production bottlenecks as the dominant constraints, followed by policy and company establishment constraints equally in second place.

Policies and institutions

Although national policy development receives considerable attention, the key role of institutions at local level is frequently overlooked, even though they are instrumental in shaping the incentives and behaviour of farmers and value chain actors. There is considerable variation across the system in the dependence on free market development. Despite improvements in business-friendly policies, agribusiness has grown less rapidly than expected since the late 2000s. Input supply and produce marketing issues persist and are unlikely to be resolved without focused national leadership.

In Ethiopia, cereals form a consistent one-third of agricultural Gross Domestic Product. Mellor and Dorosh (2010) emphasize that to expand and sustain cereal productivity, major policy changes to both seed and fertilizer markets will be required. Current policy is for fertilizer distribution to be undertaken through the cooperative movement, but expansion of access to fertilizer will require greater participation by the private sector (Spielman et al. 2010). Access to maize seed is a major problem, with little growth in the production and marketing of certified seed. There are major bottlenecks in the production of breeder, foundation and certified seed, and greater participation by the private sector in seed production is needed. Furthermore, the research sector needs to increase the amount of breeder seed produced (Mellor and Dorosh 2010).

Tripp and Rohrbach (2001) document earlier constraints in the commercial seed sector. These included a seed regulatory framework that favoured parastatal enterprises, together

with government and donor projects that provided seed to farmers for free or at subsidized prices. There has been significant deregulation of the seed sector in many countries in the maize mixed cropping zone and a consequent proliferation of private seed companies (Langyintuo 2004). However, seed producers remain heavily focused on hybrid maize seed production; few seed companies are actively involved in open pollinated maize or in improved legume seed production – with the arguable exception of groundnut seed for export. Important constraints include difficulty in raising the substantial capital required to establish a new seed business, problems associated with gaining access to improved germplasm, and government policies which prevent or discourage seed trade within the region. Where these difficulties have been overcome, the price effects can be remarkable. In Uganda, the entry of small seed companies into the industry lowered the average price of hybrid maize seed by about 40 per cent to about US\$1.20 per kg in 2008, and in Zimbabwe, reduced the price of hybrid maize seed by some 15 to 20 per cent.

Dorward et al. (2008) describe the challenge of the ‘price/productivity tightrope’, which creates an important policy dilemma in encouraging staple food intensification. The elements of the tightrope are: *producers* need high returns from investment in new technologies in order to provide them with incentives to invest in productivity-increasing technologies; and *poor consumers* need low prices for food security and welfare, and to raise real incomes to drive and support growth. Policy needs to tread a fine line between providing attractive incentives to producers to adopt new technologies and keeping cereal prices low (and preferably declining in real terms over time) so poor consumers can afford to purchase them. One of the major agricultural policies implemented across the maize mixed cropping area has been a series of structural adjustment programmes (SAPs) intended to reduce the dominance of government in the economy. The private sector players consequent on SAP implementation were unable to provide the services needed by smallholder farmers (Gabre-Madhin 2007). SAP implementation failed to address the price/productivity tightrope problem.

Short run attempts to deal with the food price tightrope problem include policies which focus on various combinations of input subsidies, output price subsidies for farmers and for consumers, and social protection to raise the incomes of the poor. The potential impacts of subsidized input costs have gained considerable attention following recent actions by the Malawi Government (Box 3.2). Subsidies can come at a major cost to other sectors of the economy (plus other inefficiencies), although the contributions to food security, poverty reduction and economic growth can be considerable (see, for example, Minde et al. 2008). An effective programme requires that the basic input technology is reliable and potentially profitable, and that the design of the input subsidy takes into account the effects on the overall rural economy. A prior and complementary investment in public goods and services (roads, agricultural research and extension, market development infrastructure) is critical. In the absence of such investment, generalized subsidies of this type have a negligible impact on poverty as the principle beneficiaries are those who already purchase inputs. Furthermore, the costs to government can quickly spiral out of control since the government does not control the international price of inputs, the exchange rate and input demand. Subsidized inputs create major incentives for cross-border trade, and uncertainty regarding government intentions seriously disrupts trade as importers and farmers wait to see the magnitude of the subsidy before placing orders (Conroy et al. 2006).

Box 3.2 The law of unintended consequences in policy

Well-intentioned government actions can exacerbate food insecurity. For six months in 2001/02, Malawi experienced a food crisis. Drought and the sell-off of the Strategic Grain Reserve were factors in the crisis, but the major cause was a sudden spike in consumer maize prices in late 2001. This problem was attributable to the adverse impact of government policy on maize supplies from the private sector. ADMARC (the public sector marketing board) had tried to stabilize maize prices by subsidizing them below prevailing market prices. As a result, private sector traders saw no opportunity to sell at a profitable price in Malawi and made few plans to import maize into Malawi. Instead there were incentives to export cheap Malawian maize to neighbouring countries where prices were higher. As the 'hungry season' progressed, ADMARC depots ran out of maize and consumers turned to private markets – which had little maize. Prices skyrocketed (Conroy et al. 2006).

Interest is growing in programs to link input subsidies with more sustainable ways of enhancing soil fertility. For example, fertilizer subsidies in Malawi are accompanied by the distribution of seeds of legume crops such as pigeon peas, and trials are underway to link the provision of fertilizers with the establishment of leguminous fertilizer trees at appropriate densities in maize fields (Garrity, D. 2014, pers. comm.).

However, in eastern and southern Africa the incentives for large firms are inadequate to address the problems of dispersed, risky and low value staple food crops markets (Barrett, 2008; Dorward and Kydd, 2004). Contract farming and interlocking transactions can be effective where there are limited numbers of produce buyers and/or there are long-term stable incentives for farmers to work in groups to access finance, advisory, input and output market services – typically involving cash crops (cotton, tea, tobacco), although there are examples where these are extended to staple food crop production (Chirwa and Kydd 2005; Chirwa et al. 2007; Jayne et al. 2004).

System performance

System performance is considered from the perspectives of productivity, resilience and sustainable development including human development outcomes. Where possible, sustainability and resilience are considered through an ecological, social and economic lens. It should be noted that about half (56 per cent) of the farm population can be rated as extremely poor (daily consumption of less than US\$1.90 in 2015) with low welfare and food security. Although many household surveys offer point estimates of system performance and national statistics report agricultural sector performance, aggregate data with which to assess farming system performance are limited.

Despite several decades of sound agricultural research, food crop productivity is low and yield gaps are large. The productivities of selected major crops in the maize mixed farming system are summarized in Table 3.4. Average yields are, in 2015, relatively low for all the crops, well below achievable yields for these crops in this farming system environment. Investments in enhancing agricultural production are generally low. Stagnant or declining agricultural productivity and limited biomass availability are important issues within the system.

Table 3.4 Productivities and yield gaps of major crops

Crop	Average yield (t/ha)	Proportion of farm (%)	Yield gap (%)
Maize	2.1	35	79
Paddy rice	2.7	5	67
Cassava	10.9	19	59
Beans	0.9	14	54
Groundnuts	1.1	6	81

Sources: FAOSTAT for yield; authors for proportion of system cultivated land; and van Velthuisen (2015, unpublished) for yield gaps.

Notes: Other root crops are grouped with cassava; and other pulses are grouped with beans.

Biotic, abiotic and socioeconomic constraints limit the productivity of maize and legumes in particular. Despite improved market access, institutional and socioeconomic constraints weaken price signals for market production. Figure 3.5 illustrates how maize yield gaps can be disaggregated by major constraints in the maize mixed system (Waddington et al. 2010). The importance of abiotic constraints – soil fertility, nitrogen and drought – is striking. At low yields the influence of biotic factors are relatively modest although crop pests and diseases are often reported as significant. Post-harvest pests are also important due to poor on-farm storage on smallholder farms. Gibbon et al. (2007) estimated that the main abiotic constraints accounted for about 1.4 t/ha maize yield loss and biotic constraints accounted for around 0.75 t/ha yield loss. Weed competition, often as a result of late planting into exhausted soils and delayed manual

Figure 3.5 Relative importance of constraints to maize yield in the maize mixed system.

Source: Waddington unpublished data.

weeding, severely limits crop yields. Increasing from a single weeding to two weedings can double yields even on low fertility soils.

Waddington et al. (2010) estimated larger yield gaps for cassava, comprising approximately 2.5 t/ha from abiotic constraints, 3 t/ha from biotic constraints and a substantial 6.5 t/ha from socioeconomic and management constraints. Wairegi et al. (2008) indicate a similar picture for banana in Uganda. Yield gaps are much smaller for sorghum and cowpeas: for sorghum Waddington et al. (2010) estimate 0.4, 0.25 and 0.6 t/ha respectively for abiotic, biotic and socioeconomic/management constraints; and for cowpea 0.2, 0.25 and 0.45 t/ha respectively. Notwithstanding differentials in market access and product prices, there is a *prima facie* case for investing more in yield gap reductions for maize and cassava rather than sorghum and cowpea. No equivalent analyses of livestock performance gaps were found in the literature.

The proportion of area under improved maize germplasm varies in the maize mixed system from 18–19 per cent in Tanzania and Ethiopia, to 72–73 per cent in Kenya and Zambia (La Rovere et al. 2013). The area under improved varieties is increasing, and the same authors forecast that proportions of improved maize will approximately double in the ‘low-adopting countries’ and increase by about one-fifth in the high-adopting countries. Nearly all the improved maize seed is distributed through small and medium seed companies (Langyintuo et al. 2010).

With the right combination of innovations (including improved germplasm and fertiliser), institutions and policies, impact is evident (Figure 3.6). Ethiopia has doubled its maize productivity since the late 1990s. Maize yields grew at an annual rate of

Figure 3.6 Maize fertilizer response was from Nsipe, Ntcheu district, in Central Malawi, with Dr Regis Chikowo illustrating the difference between recommended fertilizer (69 kg N/ha + 23 kg phosphate fertilizer) vs no fertilizer.

Source: Sieg Snapp.

Figure 3.7 **a** Relative suitability of main crops to the maize mixed system (low inputs); **b** Relative suitability of main crops to the maize mixed system (high inputs).

Source: van Velthuis et al. (2013).

68 kg/ha between 1990 and 2013 (Abate et al. 2015). The use of improved maize varieties approximately tripled between 2004 and 2013, and inorganic fertilizer use in maize approximately doubled.

A second system performance characteristic is resilience, especially in the context of increasing pressure from climate change and variability, notably droughts. Fortunately, the diversity of farm household enterprises, both crop and livestock, in the maize mixed farming system may be greater than any other African farming system, and foster ecological resilience in the face of increasing climatic stresses, shocks and biotic stresses. The presence of perennials in the system adds to ecological resilience.

The crop diversity of the maize mixed system is supported by the suitability of the major crops of the system to the soils and climatic environment (Figures 3.7a and 3.7b). About 80 per cent of this zone consists of prime land for high input farming, but only about 10 per cent of the maize mixed system is currently cultivated. Under prevailing low input management, at least a dozen crops are well adapted to this farming system (Figure 3.7a). The relative suitability of these crops increases with high inputs with good crop management (Figure 3.7b). The differences between high input and low input suitability profiles are explained by pest, disease and workability constraints in the wetter part of the farming system and, overall, due to natural soil fertility constraints.

Many species of perennials and several species of livestock, poultry and fish are very suitable for the farming system, which underscores the adaptability of the farming system to changing climate. Resilience also derives from the number and diversity of livelihood sources. The seasonal variability of livelihoods is often negatively correlated, and thus crop, livestock and off-farm income move in different cycles. Farmers and the local institutions are relatively adaptable and resilient, especially given increasing educational levels and growing access to knowledge. This is reinforced by decentralization. Thus the farming system contains a moderately high inherent level of resilience to uncertain climatic, market and policy environments.

In relation to overall system sustainability, productivity, social parameters and economic conditions (including food security) are slowly improving. While area expansion (extensification) used to underpin growth in food production, recently it has derived from a mix of area expansion and yield increase. Smallholders are responding to the increasing demand for food mainly by expanding or shifting crop fields or increasing herd sizes. In most countries fallow land has almost disappeared and continuous cropping is the norm (Twomlow et al. 2006). Marginal lands are being cultivated and remaining grazing areas and woodlands are overexploited, resulting in degradation of the resource base and lower yields per hectare. In Table 3.5 the yield gap is included for ease of reference. Of the five crops examined, annual area expansion varied from 0.5 to 4.2 per cent whereas annual yield growth rates fell in the narrower range of 1.5 to 2.2 per cent.

Another aspect of economic sustainability is the accumulation of assets. The differences in rural household wealth depend significantly on external factors such as off-farm earnings, their reinvestment in farming or commercial enterprises, and the health of working family members rather than the profitability of farm enterprises *per se*. The upper stratum of farm families has more and better farmland, more cross-bred dairy cattle and larger areas of cash crops. Irrigation is more likely to be found on medium and larger farms. They also use more fertilizer, agro-chemicals and hybrid seed, as well as taking more credit (all land-augmenting technologies). Poor households consist of landless or marginal farmers, often with no cattle (40 per cent of households), no regular off-farm earnings and no high value crops. They grow mostly local maize for home consumption and cannot afford to buy

Table 3.5 Main crop expansion and productivity growth rates

<i>Crop</i>	<i>Area expansion rate (% pa)</i>	<i>Average yield (t/ha)</i>	<i>Yield growth rate (% pa)</i>	<i>Ratio yield growth to area expansion</i>	<i>Yield gap (%)</i>
Maize	3.9	2.1	2.1	0.5	79
Rice	2	2.7	2.2	1.1	67
Cassava	0.5	10.9	2	4.0	59
Beans	4.2	0.9	1.5	0.4	54
Groundnuts	2.8	1.1	2.2	0.8	81

Source: FAOSTAT for area expansion and yield growth; van Velthuisen (2015 Unpublished data) for yield gaps.

fertilizer or hybrid seeds. A family can rapidly move from the upper stratum to poverty as a result of illness in the household (Conroy et al. 2006).

Institutional barriers constrain farm performance. With typical government policy to encourage the movement of labour out of agriculture into the modern industrial sectors (Lele et al. 2010), with remaining producers taking up adapted international knowledge and technology, this approach has meant that formal and informal links between the research and the extension services are poor, and scientists receive little feedback on farmer response to technology choices. Access to markets is constrained by high transaction costs due to the lack of infrastructure, particularly rural roads, and a constraining overall policy and regulatory environment governing market transactions (including tax regimes and licensing requirements and costs). Agribusiness is weak and development is hampered by poor service provision to smallholders and the absence of functional cooperatives and strong farmer organizations in the agricultural sector. The many landlocked countries have poor access to international markets both for imports and exports, made worse by trading, licensing, and quarantine rules, and transport restrictions (Conroy et al. 2006).

Where these constraints are addressed effectively, change is significant. Kenya, by a combination of liberalizing crop input and output markets and support to smallholder agriculture, increased smallholder fertilizer use by 34 per cent and maize yields by 18 per cent in the decade ending 2007 (Ariga and Jayne 2009). Kenya has an active and thriving indigenous seed sector. Marketing margins, of both crops and inputs, have declined

Food prices remain stubbornly high in the system. The region overall has a typical net food import of around 10 per cent or more (a proportion is emergency food aid). Drought is not the main cause of poverty; chronic poverty is strongly related to the availability of the two major resources: family labour (especially at the critical planting and weeding periods) and remittances (Conroy et al. 2006; Tiffen et al. 1994). While there is significant variation between households in access to resources, such as farm size, land quality and agricultural services and markets, a key determinant of poverty is labour availability (both human and animal traction). The poorer the household, the more the diet is dominated by cereals. In ultra-poor households, cereals represent 82 per cent of calories consumed. Urban diets are less dominated by cereals with sugar and oil products accounting for almost 20 per cent (Conroy et al. 2006; Mtimuni 2004). In significant areas of the system nearly half of rural children are stunted (measured as greater than two standard deviations from expected growth rates) compared with about a third of urban children (Conroy et al. 2006).

Strategic priorities for the system

Long-term agricultural growth prospects are promising and the potential for reduction of poverty is high. Five dominant pathways for reduction in farm household poverty (farm household poverty escape pathways) were documented by Dixon et al. (2001). Updated estimates of the relative importance of the different growth pathways to 2025 in the maize mixed system are shown in Table 3.6. This assessment shows the contributions to rural household income of on-farm diversification as well as non-farm activities – and makes explicit reference to exit from agriculture, where families enter non-farm occupations. The contrast between poverty escape pathways of extremely poor households and income growth pathways of less-poor households is clear. Intensification is an important pathway for all categories of household; off-farm income and diversification are essential for extremely poor households (intensification – increased productivity through increased efficiency of production; diversification – a change in farm practice, typically through new production or value-adding enterprises).

In the maize mixed system diversification is considered the most important pathway for escape from poverty. Most frequently, intensification precedes significant diversification, as farmers gain experience in managing production, risks and markets. As climate change-induced variability in rainfall increases, diversification gains importance in spreading risk and buffering maize yields. Compared with estimates in Dixon et al. (2001), the updated estimates suggest slightly increased importance of intensification and off-farm income, and reduced prospects for increased farm size (corresponding to the higher population density and lack of spare land to be brought under cultivation).

Strategic priorities for the maize mixed farming system for each system driver considered are summarized later in Table 3.8. For the farming system as a whole, without differentiating the extremely poor from the somewhat better off (less-poor) farm households, key strategic priorities include: increased use of livestock by the poor (wealth and risk management), increased integration of crop-livestock farming, increased use of inputs to improve soil fertility and allow allocation of crop residues to grazing rather than mulch, improved pest management, and diversification of farming.

Livestock production offers farmers great benefits in terms of food security and generating cash. Farmers use animal traction for draught power and the manure as a soil amendment.⁵ Where families do not have access to animal draught, household food security is often compromised by late planting and weeding. Selling livestock serves as a survival strategy in times of household stress (Christiaensen et al. 1995; Hoddinott 2006; Moll 2005). Farmers can also use cash from stock sales to invest to enhance overall

Table 3.6 Relative importance of household livelihood improvement strategies

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total age pop	–	56	44	100
Intensification	2	2.5	2.5	2.5
Diversification	3	3	4.5	3.5
Increased farm size	2	1	1.5	1
Off-farm income	2	2.5	1	2
Exit from agriculture	1	1	0.5	1

Source: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

farming system productivity. With skilful crop-livestock integration, the system can become more diverse, efficient and less risky. The livelihood benefits from feeding crop residues to livestock materialize relatively quickly (FAO 2010).

Addressing strategic priorities for the maize mixed system will require integrated solutions which include increased use of livestock, more integration of crop-livestock farming, expanded use of inputs to improve soil fertility, and diversification. In the extensive mixed subsystems (Table 3.3) there are opportunities for transitions to higher and more sustained levels of intensification and outputs by making more efficient use of crop-livestock interactions (Baltenweck et al. 2003; Tarawali et al. 2011), especially in relation to livestock feed. In the system generally, crop residues as livestock feed become more important as cropping expands into areas previously devoted to grazing (Alkemade et al. 2012). This comes at the significant potential cost to recycling crop residues for soil amendment (Giller et al. 2009; Valbuena et al. 2012). The form and intensity of such tradeoffs depend on local conditions. As a rule, higher crop yields will generate more residues for use for livestock and for return to the field. With the development of efficient livestock markets opportunities for sales of milk and meat will create demand for higher quality forages and feeds rather than their sole use as low quality crop residues.

Various subsidy options have been used to encourage the uptake of ‘productivity-enhancing inputs’. The intensification of maize through the ‘starter pack’ model for distribution of subsidized seed and fertilizer such as in Malawi could be considered, although a sustainable financing model has yet to be found. Box 3.3 outlines the original Malawi program, which was tightly focused on creating a sustainable, evidence-based approach. Not all poverty-reducing intensification will be sustainable (for example, intensification achieved through soil mining) and not all sustainable intensification will be poverty-reducing.

Box 3.3 The Malawi universal starter pack

The universal starter pack in Malawi (Blackie and Mann 2005) provided a subsidy for ‘best bet’ technologies (maize in Malawi) free of charge for a specific (and relatively small) land area. The intention was to provide farmers with access to improved varieties and targeted, judicious inputs that were efficient and profitable to apply. This provided a foundation for farmer experimentation, and the resources they needed to start the long haul out of poverty. The subsidy could be varied to promote crop diversification through changing the mix of inputs that are subsidized. Evaluation data showed that all participating smallholders benefited, and distribution and uptake were relatively efficient. The costs were known largely in advance and could be budgeted for. As the program was properly planned and implemented with sufficient lead time, it complemented commercial input supply and did not disrupt trade; indeed, it enhanced participation in agricultural enterprises.

Productive and profitable technologies and practices for improved soil fertility management – and more generally, improved land management and diversification – are essential. Conservation agriculture (CA) is promoted as an important technology

Table 3.7 Adoption of sustainable intensification practices

	Ethiopia	Kenya	Tanzania	Malawi	Mozambique
Maize-legume rotations	27	26	7	55	17
Maize-legume intercrop	16	73	54	32	68
Minimum tillage	24	21	30	5	21
Crop residue retention	17	48	54	47	89
Soil and water conservation (ridge, stone, soil bunds)	33	5	7	79	15

Source: Adapted from Tesfaye et al. (2017).

to achieve sustainable resource use and ensure higher crop yields (Erenstein et al. 2012; Mazvimavi and Twomlow 2009). Under this system, retaining crop residues for mulching is a key component for soil amendment and water productivity, but the full benefits materialize over time – although this can be shortened with the addition of fertilizer. A focus on fertilizer use efficiency through improved agronomic practices and enhanced cereal/legume intercropping is essential as fertilizer use efficiency is low throughout the system (Ariga and Jayne 2009; Snapp and Pound 2008). *Faidherbia albida* trees can be incorporated into the system with similar effects. The principles underlying CA will remain a key strategy for a large proportion of farmers who have the resources to invest in mechanization, agrochemicals and herbicide-resistant crop varieties (Giller et al. 2015).

Adoption of sustainable intensification practices (SIPs) (Table 3.7) can improve soil health and water retention while increasing income of adopters. Many SIPs are synergistic; for example, while improved maize varieties can increase income by 14 to 41 per cent, used with other SIPs such as zero till and residue retention, the risk of crop failure is reduced (Teklewold et al. 2013).

Biotic stress is an important cause of low productivity (Figure 3.8). The main option to address pest problems without recourse to costly and environmentally damaging pesticides, is integrated pest management (IPM), disease-resistant varieties and improved crop storage. Resistance breeding (including biotechnology) for crop pests and diseases is an essential investment.

Diversification priorities include improved development of dambo areas for vegetable production, oil seed farming with improved sunflower varieties and manual presses. Others include the promotion of intensive dairying, small-scale pig and poultry production, aquaculture and tree crops. In Kenya, labour-intensive smallholder dairy farms have evolved from previously maize-dominated systems. Improved vegetation cover and pastoral management offer prospects for carbon sequestration.

Enhancing input and output market efficiency is a major priority. Gabre-Madhin (2007) has emphasized the need for ‘getting markets right’ instead of ‘getting prices right’. Getting markets right depends on underlying institutions and supporting infrastructure, requiring guidance from a ‘visible hand’ and a concerted effort by the public sector to facilitate the role and performance of the private sector. Other critical areas include developing profitable irrigation systems, commodity exchanges, market information systems based on rural radio and short messaging systems, warehouse receipts and market-based risk management tools.

Langyintuo et al. (2010) show the dominant factors affecting the demand for improved maize seed are the price of seed and the lack of awareness by smallholder

Figure 3.8 *Striga* species limit yields in sub-Saharan Africa, notably in continuous cropped maize fields. Note that *Striga hermonthica* is important throughout west, east and central Africa, whereas *Striga asiatica* is a problem in south and east Africa.

Source: Sieg Snapp.

farmers of the potential of this seed (Figure 3.9). Innovative institutions such as private/public cooperation can provide a solution to this demand constraint for a range of species. For example, in October 2004, FIPS-Africa (a Kenya-based NGO) introduced Katumani bean (KB9) as part of their 'food security package' for drought-prone areas. The KB9 is a drought- and heat-tolerant bean developed by the public sector research agency, Kenya Agricultural Research Institute (KARI), and is suitable for areas with a short growing season. But farmers neither knew of the bean, nor could they get access to the seed. Through local stockists, FIPS set up a promotion whereby if farmers bought one of their maize mini-packs, that farmer would also get a free 250g packet of KB9 seed to try (together with the necessary agronomic information). Farmers quickly saw that the KB9 bean was well suited to their area and returned the next year to buy more seed. FIPS-Africa initially contracted a local farmer to multiply the seed to meet the immediate anticipated future demand. Today, this open-pollinated variety is produced commercially by the privately owned Western Seed Company and marketed throughout the country (Blackie et al. 2006).

The fertilizer market offers further challenges. The inefficient supply chain,⁶ combined with high costs of energy, make fertilizer prohibitively expensive to many farmers in this system. Fertilizer demand problems include affordability (given high fertilizer prices relative to the incomes of poor farmers), significant output price and weather

Figure 3.9 Smallholder farmer demand constraints in the maize seed sector.

Source: Langyintuo unpublished data.

risks, ineffective fertilizer application practices, and hence low physical grain to nutrient responses. The current policy instrument of choice, drawing on the Malawi experience, is the introduction of input subsidies. The financial and sustainable intensification benefits of these efforts are dubious. ‘Smart subsidies’ (ones that can be used for diversification or regenerative options or as vouchers redeemable from certified rural stockists) can develop, rather than undermine, rural agricultural input markets that serve the poor (Morris et al. 2007).

Ariga and Jayne (2009) point to the potential for imaginative public/private partnerships. The government has a critical strategic role in the early stage of development, especially in remote areas, because it is unlikely that private traders will deliver research, extension and credit services to smallholders, especially to those in remote areas (see Eicher 2004 on Zimbabwe). This has to be complemented by effective support to the infant private sector by creating an enabling environment for business development – including providing macro-economic stability, investment-friendly policies and infrastructure development.

New technologies such as CA and agroforestry require further verification under local conditions (Andersson and Giller 2012; Giller et al. 2009), with research focusing on flexible, judicious input use along with supporting farmer adaptation to local priorities (Giller et al. 2011; Snapp et al. 2003).

The availability of information to small farmers is critical in both intensification and diversification. New technologies (CA, agroforestry and IPM) are knowledge intensive. Farmers need the means to judge the best avenues for livelihood improvement for their circumstances. Giller et al. (2011) have developed the Nutrient Use in Animal and Cropping systems – Efficiencies and Scales (NUANCES) framework, which offers a structured approach to identify the ‘best-fit’ technologies targeted to specific types of farmers and to clear niches within their farms. Investment in farmer training, including

the revitalization of farmer training institutes and complementary village and field level education, is indicated.

The rapid development of modern ICTs offers the prospect of a quantum leap in the availability of technical and market information to farmers. Farm production could benefit from the rapid dissemination of information on disease outbreaks, as well as from market information. Financial transactions have been revolutionized in Kenya by M-PESA. As the sector develops, the prospects for job creation in rural chains, especially produce and input chains, will increase (see, for example, Smith et al. 2013). Problems of access to good quality open pollinated seeds can be addressed by promoting farmer-based seed multiplication and agribusiness development (Box 3.4).

Box 3.4 Seed supply systems

The seed sector in the maize mixed farming system faces problems which are common to the countries in eastern and southern Africa (but contrast with those of west and central Africa). The public sectors, which have been the engine behind development of the majority of new crop varieties, do not have adequate resources to meet the costs of bulking and distributing seeds of such varieties. The private sector faces many constraints in investing in the improved seed systems for smallholders (Langyintuo et al. 2010). Naturally, the context varies a lot from crop to crop. Through DTMA and SIMLESA, CIMMYT has worked closely with NARS and seed companies to develop a road map for maize seed system development. Through the program ‘Tropical legumes II’, ICRISAT has focused on community seed systems for pulses, including pigeon pea. In Zambia, CARE has supported a community-based seed bulking and distribution scheme for drought tolerant maize and sorghum – supported by agronomy, seed handling and post-harvest storage extension information. AGRA has also invested in strengthening private sector seed companies.

Perhaps the most strategic intervention is refocusing public policy frameworks for developing agricultural businesses and strengthening institutions to support private enterprise. In one sense, there are opportunities for improved policies in the strategic interventions outlined in Table 3.8, not least markets, trade and agribusiness. Policy makers need to address tradeoffs, of which the most challenging in the maize mixed system (and other African farming systems) is the balance between attractive incentives for producers to adopt new technologies and the need to keep cereal prices low enough such that staple foods are readily accessible to poor consumers, both urban and rural. Effective policy making requires a sound evidence base and ideally adopts a multi-sectoral approach, including agriculture, water, health and transport. The most critical long-term policy decisions for the maize mixed systems are the levels of public investments in agricultural research, rural infrastructure and support to agribusiness. Common short-term policy measures include subsidies for inputs, produce and consumption. Interest is growing in public programs to link agricultural intensification with social protection, and input subsidies with more sustainable ways of enhancing soil fertility. The availability of information to small farmers will be a critical factor in creating change within the system.

Table 3.8 Summary of strategic priorities for the maize mixed system

<i>Drivers of farming system evolution</i>	<i>Key interventions</i>	<i>Leading implementers</i>	<i>Implications for farming system structure and function</i>
Population (increasing), hunger and poverty (reducing)	Improved labour markets and more non-farm job opportunities. Market mechanisms for famine relief, rehabilitation and recovery.	Ministries. World Food Program (WFP). Businesses. NGOs.	Wider access to off-farm employment, income and even opportunities to exit agriculture. Rural urban migration. Inflow of farmers from lower potential agropastoral and pastoral farming systems. Reduced population pressure on land. Increased (1) operated farm size, (2) household income and opportunity cost of labour, (3) yield and income stability and (4) farming system resilience.
Natural resources (improving) and climate (changing)	Integrated participatory natural resource management including soil fertility management. Improved forest and grassland management. Better adaptive mechanisms to variable climate.	Agricultural extension. Agricultural research. NGOs. Communities.	Improved forest, land and water resource base. Reduced degradation, erosion and flooding. Increased carbon sequestration. Increased land values. Increased crop and livestock productivity. Reduced conversion of forest and grassland to cropping. Reduced substitution of low fertility requiring and low value crops. Increased production and income stability with climate adaptation. Better system resilience.
Energy (increasing)	Integration energy-agriculture. Natural regeneration, community woodlots and agroforestry. Labour-saving technologies and equipment (mechanization). Expanded grids. On-farm solar energy production and storage.	Communities. NGOs. Business. Ministries.	Increased and lower cost energy inputs to production, value-addition, on-farm storage and transport to market. Increased perennials and better ground cover. Better labour efficiency. Increased farm income from intensification, value-adding and energy production. Improved lifestyles and livelihoods.
Human and social capital (increasing)	Information platforms and dissemination. Invest in ICTs and mobile phones. Target women and girls. Farmer networking and learning. Strengthen farmer training. Support innovation platforms.	Universities and colleges. NGOs. Extension. Media (radio, TV).	More knowledgeable farm managers. Greater benefits to women. Better resource and input management. More market-oriented and diversified systems. Increased prevalence of knowledge-intensive production systems. Reduction of credit and knowledge constraints. Increased farmer innovation. Farmers contributing to pest surveillance, weather models and production reporting. Faster adoption of innovations.

Science and technology (improving)	Interdisciplinary systems research approach. Engagement with business. Rebalanced research priorities towards diversification, nutrient-dense and labour-reducing innovations. Support innovation platforms for farmer adaptation of technologies and farmer innovation.	Agricultural research. Farmer groups and innovation platforms. Universities and colleges. Agribusiness.	Increased crop, livestock and tree productivity. Better resource management. Increased input use efficiency. Improved control of pests and diseases. Better system fit of new technologies. Rebalanced enterprise pattern to new varieties and technologies (along with market orientation). Initial specialization. In general, a more diversified and integrated market-oriented farming system. Increased and stabilized farm income.
Trade and markets (growing)	Invest in transport, processing and storage infrastructure. Reduce barriers to cross-border agricultural trade. Improved market information including ICTs. Expanded financing, savings and banking services. Strengthened insurance markets. Incentives for business investment	Agribusiness. Ministries.	Wider choice and better informed production and marketing decisions. Increased farm gate produce prices. Wider availability of inputs at reduced costs. Increased local trade of intermediate products, e.g. fodder. Greater comparative advantage and increased competitiveness of the systems. Increased resource, labour, input and total factor productivity. Increased farm household incomes and capital for farm improvement and expansion. Improved risk management. Growth of rural economy and initial rural transformation.
Policies and institutions (improving)	Harmonize agricultural and related rural policies, institutions and technologies. Improve land tenure and markets, and water management. Enable business engagement. Strengthen community institutions for common property management. Massive capacity building for policy implementation staff. Monitoring of policy implementation and impact.	Ministries for formulation and regional/local offices for decentralized implementation.	Synergies between well-calibrated policies, institutions and technologies stimulates farm productivity and sustainable land and water management. Increased benefits to women and smaller size/poorer farmers from inclusive policies and institutions, increasing incomes and reducing rural inequality. Increased rural wage rates. Lower cost and wider choice in inputs. Increased productivity. Increased farm gate grain and livestock prices.

Investment in farmer training, including the revitalization of farmer training institutes and complementary village and field level education, is imperative.

Conclusion

Food insecurity, hunger and poverty are extensive, especially among the 80 per cent of the poor who depend on farming for their main livelihood in the maize mixed farming system. There are islands of successful intensification and diversification. A broad-based reduction of poverty is feasible with better policy and institutional environments to boost agricultural productivity. The urban bias against agriculture results in a poor supply of public goods to rural areas. Transaction costs are high, which severely reduces rural incomes. Past investments in agricultural research and extension have been mixed, while terms of trade have been declining. Moreover, poor governance, civil strife, degenerating law and order situations in some areas, as well as widespread gender inequality, low levels of schooling, and HIV/AIDS, are all of deep concern.

The relative abundance of natural resources in the maize mixed system provides the basis for pro-poor agricultural development. This requires appropriate adjustments in national policies, reorientation of institutions and adequate provision of public goods and services. The strategic goal is broad-based inclusive agricultural growth benefiting the poorer sections of each community. Access to agricultural resources by poor farmers will create viable small family farms. Components include: market-based land reform, strengthened public land administration and functional community land tenure. Increasing the competitiveness of small and poor farmers will build capacity to exploit market opportunities. Components include: improved production technology, diversification, processing, upgrading product quality, linking production to niche markets, and strengthening support services including market institutions based on public-private partnerships. Household risk management will reduce the vulnerability of farm households to natural and economic shocks. Components include: drought-resistant and early varieties and hardy breeds, improved production practices for moisture retention, insurance mechanisms and strengthening traditional and other risk-spreading mechanisms.

Improved institutions, including policies and public investment portfolios, are important drivers of improved rural food and nutrition security for the maize mixed system. Better public funding of agricultural research, in particular on sustainable intensification, and transport infrastructure can generate expanded technological and market opportunities for intensification and diversification of farms. Pricing policy has to balance incentives for the adoption of new technologies with the need for affordable and reliable maize and legumes for poor consumers, both urban and rural. Support for business investments into input and produce chains, including transport, storage and processing of maize, legumes and livestock, will create new market opportunities. The availability of technical and market information to small farmers will be a critical factor in farm system transformation which, along with expanded labour markets and off-farm income opportunities, will underpin improved food security and livelihoods in the maize mixed farming system.

Notes

- 1 South Africa was a notable exception where the average farm size continues to increase.
- 2 For example, in Ethiopia, where the constitutional provisions leave land ownership in the hands of the government, and farmers are only given use rights to land under long-term lease arrangements, the annual average growth in agriculture has been around 6 per cent in recent years.

- 3 SIMLESA – Sustainable Intensification of Maize–Legume Cropping Systems for Food Security in Eastern and Southern Africa Program is supported by ACIAR and managed by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with the sub-regional and national research organizations, Australian universities and other centres.
- 4 Corridor disease (*Theileria parva*) infection in cattle, which caused large losses in the mid-1990s, is considered a serious potential emerging disease (Mbizeni et al. 2013).
- 5 Nutrient quality of many of these manures is poor. The main effect is the addition of organic matter to the soil.
- 6 Inefficient bulk cargo and bagging handling operations at Dar es Salaam can increase the cost of imported fertilizer by 40 per cent by the time it has left the port.

References

- Abate, I., Shiferaw, B., Gebeyehu, S., Amsalu, B., Negash, N., Assefa, K., Eshete, M., Aliye, S. and Hagmann, J. (2011) A systems and partnership approach to agricultural research for development. *Outlook on Agriculture* 40(3): 213–20.
- Akinnifesi, F., Ajayi, O., Sileshi, G., Chirwa, P. and Chianu, J. (2010) Fertilizer tree systems for sustainable food security in the maize-based production systems of Eastern and Southern Africa Region: A review. *Journal of Sustainable Development* doi:10.1051/agron/2009058.
- Alkemade, R., Reid, R.S., van den Berg, M., de Leeuw, J. and Jeuken, M. (2012) *Assessing the Impacts of Livestock Production on Biodiversity in Rangeland Ecosystems*. www.pnas.org/cgi/doi/10.1073/pnas.1011013108.
- Andersson, J. and Giller, K. (2012) On heretics and God's blanket salesmen; Contested claims for Conservation Agriculture and the politics of its promotion in African smallholder farming. In Sumberg J. and Thompson J. (eds) *Contested Agronomy: Agricultural Research in a Changing World*. Earthscan.
- Ariga, J. and Jayne, T. (2009) Private sector responses to public sector reforms. *IFPRI Discussion Paper 00921*. IFPRI.
- Baijukya, F., de Ridder, N., Masuki, K. and Giller, K. (2005) Dynamics of banana-based farming systems in Bukoba district, Tanzania: Changes in land use, cropping and cattle keeping. *Agriculture, Ecosystems and Environment* 106: 395–406.
- Baltenweck, I., Staal, S., Ibrahim, M.N.M., Herrero, M., Holmann, F., Jabbar, M., Manyong, V., Patil, B.R., Thornton, P., Williams, T., Waithaka, M. and de Wolff, T. (2003) *Crop-Livestock Intensification and Interactions across Three Continents: Main Report. System-wide Livestock Program (SLP) Project on Transregional Analysis of Crop-Livestock Systems*. International Livestock Research Institute (ILRI), Nairobi.
- Barrett, C. (2008) Smallholder market participation: concepts and evidence from eastern and southern Africa. *Food Policy* 32: 210–219.
- Bezabih, M., Holden, S.T. and Mannberg, A. (2016) The role of land certification in reducing gaps in productivity between male- and female-owned farms in rural Ethiopia. *Journal of Development Studies* 52(3): 360–376.
- Blackie, M. and Mann, C. (2005) The origin and the concept of the starter pack. In Levy S. (ed.) *Starter Packs: A Strategy to Fight Hunger in Developing Countries*. CABI.
- Blackie, M., Thangata, P., Kelly, V. and Makumba, W. (2006) Agricultural sustainability in Malawi: Transforming fertilizer subsidies from a short-run fix for food insecurity to an instrument of agricultural development – Technical and policy considerations. *Paper presented at the International Association of Agricultural Economists Conference*, Gold Coast, Australia. 12–18 August 2006.
- Cabral, L. and Scoones, I. (2006) What role for ministries of agriculture in the 21st century? *Policy Brief 10*. The Futures Agricultural Consortium.
- Chirwa, E., Dorward, A. and Kydd, J. (2007) *Reforming the Smallholder Coffee Sector in Malawi: A Case Study of Smallholder Commercialisation*. Working paper, Future Agricultures.
- Chirwa, E. and Kydd, J. (2005) *Study on Farmer Organisations in Smallholder Tea in Malawi*. Working paper. Imperial College London.

- Christiaensen, L., Tollens, E. and Ezedinma, C. (1995) Development patterns under population pressure: Agricultural development and the cassava-livestock interaction in smallholder farming systems in Sub-Saharan Africa. *Agricultural Systems*, 48(1): 51–72.
- Conroy, A., Blackie, M., Whiteside, A., Malewezi, J. and Sachs, J. (2006) *Poverty, AIDS and Hunger in Malawi: Breaking out of Malawi's Poverty Trap*. Palgrave Macmillan.
- Dixon, J., Gulliver, A. and Gibbon, D. (2001) *Farming Systems and Poverty: Improving Farmer's Livelihoods in a Changing World*. FAO and World Bank. www.fao.org/farmingsystems/.
- Dorward, A., Chirwa, E. and Poulton, C. (2008) Improving access to input and output markets. *Paper Prepared for the Southern Africa Regional Conference on Agriculture: Agriculture-led Development for Southern Africa – Strategic Investment Priorities for Halving Hunger and Poverty by 2015*. 8–9 December 2008, Gaborone, Botswana.
- Dorward, A. and Kydd, J. (2004) The Malawi 2002 food crisis: The rural development challenge. *Journal of Modern Africa Studies* 42: 231–240.
- Ebanyat, P., de Ridder, N., de Jager, A., Delve, R., Bekunda, M. and Giller, K. (2010) Drivers of land use change and household determinants of sustainability in smallholder farming systems of Eastern Uganda. *Population and Environment* 31(6): 474–506.
- Eicher, C.K. (2004) Flashback: Fifty years of donor aid to African agriculture. Revised version of a paper presented at an *International Policy Conference, Successes in African Agriculture: Building for the Future*, sponsored by InWent, IFPRI, NEPAD and CTA, Pretoria, South Africa, 1–3 December 2003.
- Erenstein, O., Sayre, K., Wall, P., Hellin, J. and Dixon, J. (2012) Conservation agriculture in maize and wheat based systems in the (sub)tropics: Lessons from adaptation initiatives in South Asia, Mexico and Southern Africa. *Journal of Sustainable Agriculture* 36(2): 180–206.
- FAO. (2010) An international consultation on integrated crop-livestock systems for development. *Integrated Crop Management* 13. FAO.
- FAO. (2011) *Save and Grow. A Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production*. FAO.
- FAOSTAT (undated) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- Gabre-Madhin, E. (2007) Making markets work for the poor: the challenge in the age of globalization. In Reuben, R., Pender J. and Kuyvenhoven A. (eds) *Sustainable Poverty Reduction in Less Favoured Areas*. CABI.
- Garrity, D., Akinnifesi, F., Ajayi, O., Sileshi, G.W., Mowo, J.G., Kalinganire, A., Larwanou, M. and Bayala, J. (2010) Evergreen agriculture: A robust approach to sustainable food security in Africa. *Food Security*, 2(3): 197–214.
- Gibbon, D., Dixon, J. and Flores, D. (2007) *Beyond Drought Tolerant Maize: Study of Additional Priorities in Maize*. Report to Generation Challenge Program. Impacts, Targeting and Assessment Unit, CIMMYT.
- Giller, K., Tittonell, P., Rufino, M., Van Wijk, M., Zingore, S., Mapfumo, P., Adjei-Nsiah, S., Herrero, M., Chikowo, R., Corbeels, M., Rowe, E., Bajjukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W., Sanogo, O., Misiko, M., de Ridder, N., Karanja, S., Kaizzi, C., K'ungu, J., Mwale, M., Nwaga, D., Pacini, C. and Vanlauwe, B. (2011) Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural Systems* 104: 191–203.
- Giller, K.E., Andersson, J.A., Corbeels, M., Kirkegaard, J., Mortensen, D., Erenstein, O. and Vanlauwe, B. (2015) Beyond conservation agriculture. *Frontiers in Plant Science* 6, <https://doi.org/10.3389/fpls.2015.00870>.
- Giller, K.E., Witter, E., Corbeels, M. and Tittonell, P. (2009) Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research* 114: 23–34.
- Hoddinott, J. (2006) Shocks and their consequences across and within households in rural Zimbabwe. *Journal of Development Studies* 42(2): 301–321.
- Homann-Kee Tui, S., Tanganyika, J., Bandason, E., Maute, F., Nkomboni, D., Mpofu, N., Nisrane, F., van Rooyen, A.F., Gondwe, T., Dias, P., Ncube, S., Moyo, S. and Hendricks, S.

- (2012) *Optimizing Livelihood and Environmental Benefits from Crop Residues in Smallholder Crop-Livestock Systems in sub-Saharan Africa and South Asia: Southern Africa Case Study*. Regional SLP report on the socio-economic analysis. ICRISAT.
- IFA. (2002) *Water Availability and Fertilizer Use*. International Fertilizer Industry Association position paper
- Jayne, T., Yamano, T., Weber, M., Tschirley, D., Benfica, R., Neven, D., Chapoto, A. and Zulu, B. (2004) *Smallholder Income and Land Distribution in Africa: Implications for Poverty Reduction Strategies*. MSU International Development Paper No. 24. Michigan State University.
- Langyintuo, A. (2004) *Challenges of the Seed Sector of Southern Africa*. CIMMYT. www.cimmyt.org/gis/rfseedsafrica.
- Langyintuo, A., Mwangi, W., Diallo, A., MacRobert, J., Dixon, J. and Bänziger, M. (2010) An analysis of the bottlenecks affecting the production and deployment of maize seeds in Eastern and Southern Africa. *Food Policy* 35: 323–331.
- La Rovere, R., Tahirou, A., Genti, K., Zhe, G., Mwangi, W., MacRobert, J. and Dixon, J. (2013) Economic, production and poverty impacts of investing in maize tolerant to drought in Africa: An ex ante assessment. *Journal of Developing Areas* 47(2): 213–226.
- Lele, U., Pretty, J., Terry, E. and Trigo, E. (2010) Transforming agricultural research for development. *Report for the Global Conference on Agricultural Research*, 28–31 March 2010. Montpellier, France.
- Mallawaarachchi, T., Deneke, T.T. and Addai, D. (2013) *Farm Size Dynamics in East and Southern Africa: Implications for Research Priority Setting*. Final Report of a Small Research Activity, Canberra: ACIAR.
- Mallawaarachchi, T., Deneke, T.T. and Addai, D. (2014) Farm size dynamics in East and Southern Africa: Implications for research priority setting – Synthesis report. In Telahun, D. (ed.) *Farm Size Dynamics in East and Southern Africa*. Amhara Region Agricultural Research Institute (ARARI), pp. 1–30.
- Mazvimavi, K. and Twomlow, S. (2009) Socioeconomic and institutional factors influencing adoption of conservation farming by vulnerable households in Zimbabwe. *Agricultural Systems* 101(1–2): 20–29.
- Mbizeni, S., Potgieter, F.T., Troskie, C., Mans, B.J., Penzhorn, B.L. and Latif, A.A. (2013) Field and laboratory studies on Corridor disease (*Theileria parva* infection) in cattle population at the livestock/game interface of uPhongolo-Mkuze area, South Africa. *Ticks and Tick-borne Diseases* 4: 227–234.
- Mellor, J. and Dorosh, P. (2010) *Agriculture and the Economic Transformation of Ethiopia*. Ethiopia Support Strategy Programme 2 Working Paper ESSP2 010. IFPRI.
- Minde, I., Jayne, T., Crawford, E., Ariga, J. and Govereh, J. (2008) *Promoting Fertilizer Use in Africa: Current Issues and Empirical Evidence from Malawi, Zambia, and Kenya*. Working Paper for Re-SAKSS/Southern Africa.
- Moll, H.A.J. (2005) Costs and benefits of livestock systems and the role of market and non-market relationships. *Agricultural Economics* 322: 181–193.
- Morris, M., Kelly, V., Kopicki, R. and Byerlee, D. (2007) *Fertiliser Use in Africa: Lessons Learned and Good Practice*. International Bank for Reconstruction and Development.
- Mtimuni, B. (2004) *Situational Analysis of Food Insecurity and Malnutrition in Malawi*. Background Paper commissioned by the Ministry of Agriculture for the preparation of the National Food Security and Nutrition Policy.
- Nyagumbo, I., Munamati, M., Mutsamba, E.F., Thierfelder, C., Cumbane, A. and Dias, D. (2015) The effects of tillage, mulching and termite control strategies on termite activity and maize yield under conservation agriculture in Mozambique. *Crop Protection* 78: 54–62.
- Ryan, J.G. and Spencer, D.C. (2001) *Future Challenges and Opportunities for Agricultural R&D in the Semi-Arid Tropics*. ICRISAT.
- Shiferaw, B., Prasanna, B.M., Hellin, J. and Bänziger, M. (2011) Crops that feed the world 6: Past successes and future challenges to the role played by maize in global food security. *Food Security* 3: 307–327.

- Smith, J., Sones, K., Grace, D., MacMillan, S., Tarawali, S. and Herrero, M. (2013) Beyond milk, meat, and eggs: Role of livestock in food and nutrition security. *Animal Frontiers* 3(1): 6–13.
- Snapp, S. and Pound, B. (eds) (2008) *Agricultural Systems: Agroecology and Rural Innovation for Development*. Elsevier.
- Snapp, S.S., Blackie, M.J. and Donovan, C. (2003) Realigning research and extension to focus on farmers' constraints and opportunities. *Food Policy* 28: 349–363.
- Spielman, D., Byerlee, D., Alemu, D. and Kelemework, D. (2010) Policies to promote cereal intensification in Ethiopia. *Food Policy* 35: 185–194.
- Tarawali, S., Herrero, M., Descheemaeker, K., Grings, E. and Blümmel, M. (2011) Pathways for sustainable development of mixed crop livestock systems: Taking a livestock and pro-poor approach. *Livestock Science* 139(1–2): 11–21.
- Teklewold, H., Kassie, M., Shiferaw, B. and Köhlin, G. (2013) Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics* 93: 85–93.
- Tesfaye, K., Kassie, M., Cairns, J.E., Michael, M., Stirling, C., Abate, T., Prasanna, B.M., Mekuria, M., Hailu, H., Bahadur Rahut, D., Erenstein, O. and Gerard, B. (2017) Potential for scaling up climate smart agricultural practices: Examples from Sub-Saharan Africa. In Leal Filho et al. (eds) *Climate Change Adaptation in Africa: Fostering Resilience and Capacity to Adapt*. Berlin: Springer International Publishing AG, pp. 185–203.
- Thornton, P.K., Jones, P.G., Alagarwamy, G., Andresen, J. and Herrero, M. (2010) Adapting to climate change: Agricultural system and household impacts in East Africa. *Agricultural Systems* 103: 73–82.
- Tiffen, J., Mortimore, M. and Gichuki, F. (1994) *More People, Less Erosion*. Oxford University Press.
- Tripp, R. and Rohrbach, D. (2001) Policies for African seed enterprise development. *Food Policy* 26: 147–161.
- Twomlow, S.J., Steyn, T.J. and Du Preez, C.C. (2006) Dryland farming in southern Africa. Chapter 19. In *Dryland Agriculture*, second edition. Agronomy Monograph No 23. American Society of Agronomy, pp. 769–836.
- Valbuena, D., Erenstein, O., Homann-Kee Tui, S., Abdoulaye, T., Claessens, L., Duncan, A.J., Gérard, B., Rufino, M.C., Teufel, N., van Rooyen, A. and van Wijk, M.T. (2012) Conservation agriculture in mixed crop-livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. *Field Crops Research* 132: 175–184.
- van Koppen, B. (2001) *A Gender Performance Indicator for Irrigation: Concepts, Tools and Applications*. Research Report 59, International Water Management Institute (IWMI).
- van Velthuizen, H., Fischer, G. and Hizsnyik, E. (2013) *Technical Annex: FS Characterization with GAEZ Data. The African Farming Systems Update Project: Farming Systems and Food Security: Priorities for Science and Policy under Global Change*. IIASA.
- Waddington, S.R., Li, X., Dixon, J., Hyman, G. and de Vicente, M.C. (2010) Getting the focus right: Production constraints for six major food crops in Asian and African farming systems. *Food Security* 2(1): 27–48.
- Wairegi, L., van Asten, P., Tenywa, M. and Bekunda, M. (2008) Abiotic constraints override biotic constraints in East African highland banana systems. *Field Crops Research* 117: 146–153.

4 The agropastoral farming system

Achieving adaptation and harnessing opportunities under duress

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Key messages

- Close to 100 million farmers, half of them extremely poor, live in the African agropastoral farming system characterized by highly variable, semi-arid climate and poor soil conditions. Agropastoral livelihoods rely on the integration of crop and pastoral livestock production and soil, crop and tree-based adaptive management practices that optimize resources and reduce risk and vulnerability.
- Key trends include rapid population growth and urbanization, resulting in the development of domestic markets, increased monetization of the food system including for the poorest, improved access to information, and climate change. Changes in natural resources management include reduced fallow area and duration, increased competition between cropping and pastoral activities, sedentarization of mobile pastoral production and farmer-managed regeneration of tree cover on farms.
- Yield gaps can be bridged with soil and water conservation technologies combined with both organic and inorganic amendments, yet intensification is constrained by system bottlenecks in agricultural chains from production to marketing. Sustainable intensification requires systemic investment planning and integrated multi-stakeholder intervention approaches along the value chain that contribute to maximizing profitability and minimizing risk and for farmers.
- Key investment priorities include opportunities for the youth, enhancing women's access to land resources, a strengthened role of farmer organizations in agricultural value chains, effective scaling-up approaches for adapted technology and market innovations, specific policy focus on the development of sorghum, millet, cowpea and groundnut, improved urban-rural linkages and enabling policies.

Summary

The agropastoral farming system in Africa is defined by a length of growing period (LGP) between 75 and 165 days, semi-arid conditions and the combination of crop and pastoral livestock production. It includes four geographically defined regions or subsystems. Vulnerability to a variety of risks linked to highly seasonal climate, poor soils, pests, price volatility and conflict is widespread and involves adaptations in farming and livelihood

activities. The maintenance of scattered, intercropped multipurpose woody perennials contributes to diversified production, expanded nutrient cycles and more resilient livelihoods. Challenges for the farming system include high population growth rates, land use saturation, decline of fallowing practices, large youth employment gaps, climate change, as well as land and resource access and tenure constraints especially for women. Sorghum and millet as well as cowpea and groundnut are key but underdeveloped crops grown with few inputs and with low marketable surpluses. In contrast to cash crops, intensification of these food crops has been limited. Low adoption of new technology is mostly related to their low profitability and perceived risks rather than available capital. Therefore, most significant and sustainable forms of improvements in the agropastoral system will come from system-oriented interventions that complement technological intensification (crop-livestock associations, soil and water conservation techniques, agroforestry, improved seeds, targeted fertilization, etc.), with stronger producer organizations, interventions for improved marketing and new commercial outlets for sorghum and millet. The latter should be supported through public-private partnerships (producer groups, finance, agriprocessors) to promote value chains and a conducive policy environment.

Overview of the farming system and subsystems

The agropastoral farming system extends over 443 million ha in semi-arid regions of northern Africa, the Sudano-Sahelian belt stretching across western and central Africa as well as eastern and southern Africa, of which 68 million ha are spatially analysed as cultivated. The farming system is defined by an LGP of between 75 and 165 days, semi-arid conditions and the combination of crop production and pastoral livestock production. It is the predominant farming system in some twenty-five African countries (Figure 4.1). While rainfall seasonality is relatively reliable, the volume and distribution of rainfall in time during the rainy season(s) and space is highly unpredictable, with significant risks of crop failure. There is intense competition for resources that shape local land management systems and livelihoods. Farmers adapt to uncertain environmental conditions through a range of adaptive management practices related to livestock, soil, crop and woody plant resources. The average travel time to market of 7.1 hours is lower than in other farming systems, but the quality of markets and rural services (including roads, schools, health services, utility grids) is generally poor.

In West-Central Africa, the core system is located in the Sudano-Sahelian climatic zone where rainfall occurs in a single wet season and ranges from approximately 450 to 800 mm. In East Africa, the agropastoral system is found in the semi-arid lowlands located east of the Central Highlands, south of the Ahmar mountains and in the northwestern region in Ethiopia, in the Bay semi-arid regions of Somalia, the dry parts of central to southern Kenya and southwestern Uganda, and the dry mid-altitude central region of Tanzania. In southern Africa, the system occurs in the semi-arid areas of the Limpopo, Okavango and Zambezi river basins (Figure 4.2). This area is characterized by a single wet season with frequent mid-season dry spells and high temperatures. In most parts, the southern African region is suitable for extensive livestock production, game ranching and drought tolerant crops such as sorghum and millets.

Rainfall

In West and Central Africa rainfall is strictly monomodal and occurs mainly from June to September (peak in August), with small amounts in May and October. The November to May dry season is divided into a cool part (December to February) and a warm part

Figure 4.1 Map of the agropastoral farming system in Africa.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Table 4.1 Basic system data (2015): agropastoral farming system in Africa

Farming system descriptor	Data
Total human population (million)	193.9
Agricultural population (million)	98.4
Total system area (million ha)	443.0
Cultivated area (million ha; % of total area)	67.8; 15
Irrigated area (million ha; % of cultivated area)	1.5; 2
Total livestock population (million TLU)	72.1
Major agroecological zone	Tropical warm semi-arid
Length of growing period (average, days; core range, days)	130; 75–165
Access to services (low/medium/high)	Low-medium
Distance to 50k market (average, hr; core range, hr)	7.1; 2–10
Agricultural population density (persons/total area; persons/cultivated area)	0.22; 1.5
Livestock density (TLU/total area; TLU/cultivated area)	0.16; 1.1
Standard farm/herd size (cultivated area/household, TLU/household)	3.8; 4.0
Extreme poverty (% of rural population)*	53*

Sources: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Note: * for sub-Saharan Africa only.

Figure 4.2 Cattle form the backbone of livelihoods in the southeastern lowveld of Zimbabwe Limpopo Valley. They are used for draught power and milk production; most importantly cattle are traded during drought years for maize with farmers in less affected areas. Southeastern Zimbabwe is known as the sweet veld because the bulk of grasses found in this region do not lose nutritional value to levels below maintenance for cattle. Browsing of Mopane tree leaves helps close the dry season food gap when grass biomass is insufficient.

Source: Chrispen Murungweni.

(March to May). Rainfall seasonality is quite predictable, although the start and end of the rainy season varies. However, the volume and distribution of rainfall in time within the wet season and space are highly variable. In West Africa, rainfall variability increases as rainfall decreases. In southern Africa, rainfall is less strictly monomodal than in West and Central Africa with a peak in the month of December and transition to subtropical climate in South Africa. In East Africa, rainfall is mostly bimodal, which makes a large difference in spreading the growing season over a much longer period. Across the whole system, rainfall is generally characterized by a variable start and end of the season, and extended mid-season dry spells which often coincide with crop pollination, thereby depressing yield. Rainfall variability, along with soils poor in nutrients and physical properties, except volcanic silt in East Africa, plays a major role in production risk. Food insecurity is chronic.

Main crops

There are marked differences in the cultivated area of sorghum, millet and maize between regions (Table 4.3). A relatively short growing season in West Africa dictates

that millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) are the dominant crops there, with over 82 per cent of the subsystem's cultivated area. In the eastern and southern African parts of the farming system, maize (*Zea mays*) has by far the highest area with 42 per cent and 35 per cent, respectively. In parts of Botswana and northern Namibia where rainfall is lowest, pearl millet is the dominant cereal, accounting for 60 per cent of cereal crops grown.

Other crops include cowpea (*Vigna unguiculata*), fonio (*Digitaria exilis*) and groundnut (*Arachis hypogea*) on the sandier soils. Sesame (*Sesamum indicum*), bambara nut (*Voandzeia subterranea*), roselle (*Hibiscus sabdariffa*), water melons, vegetables, rice (*Oryza spp.*) as well as sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*) and even potato (*Solanum tuberosum*) are grown in low-lying areas, river delta areas and along rivers and streams. Cotton (*Gossypium hirsutum*) and tobacco (*Nicotiana tabacum*) are also important in some specific areas. In the Mediterranean North African agropastoral region main crops include wheat (*Triticum spp.*), barley (*Hordeum vulgare*), and legumes including alfalfa (*Medicago sativa*).

Intensifying nutrient management extends the production potential of crops in shorter LGPs. The increase in maize cultivation in the agropastoral and other farming systems (Chapters 6 and 7 this volume) is due to the existence of accessible and well-developed markets for maize, lower labour requirements for its production and processing, less bird depredation, and its suitability for preparing the staple dish (sadza/ugali/nsima).

Sorghum, millet and maize are the main cereals in daily diets. They are prepared in various forms (tô/ugali, beverages, couscous, etc.). Legumes, such as groundnut and cowpea, are a source of protein, while also providing cash from sale of the seeds and fodder from haulms for livestock. Although rural farmers mainly grow sorghum and pearl millet for food and home brewing, production for sale is also common by both smallholder and large-scale farmers, under contract from brewers, for example in South Africa and Zimbabwe. In these countries, sorghum and millet are also used as feed in the livestock industry.

On-farm tree resources

In most of the agropastoral region, farmers grow crops under an open, permanent upper story of scattered trees (in the rainier areas) and shrubs (in the drier areas) of varying density. These are managed as an integrated parkland system characterized by one or a few dominant woody species and many secondary ones whose composition varies according to local ecology and farmer preferences (Boffa 1999). Farmers have used this agro-ecological adaptation to diversify production (food, fodder, fuel, wood for tools and furniture, medicine, etc.), enhance services (soil fertility, shade and microclimate moderation, fencing and field delineation) and improve system sustainability. Parkland establishment occurs through farmer selection and protection of valuable trees in the woodland or fallow vegetation when they first clear a field. Trees will then develop further through alternating cycles of cultivation and fallows. Building on the traditional coppicing of shrubs during land preparation for crops, farmer-managed natural regeneration (FMNR) of trees and shrubs in croplands has been promoted, to a greater extent in the drier areas, to restore barren and degraded lands, taking advantage of the sparse vegetation to re-establish woody cover. The documented increase of woody cover in cropland over past decades in spite of the expansion of cultivated areas and a reduction in fallow areas and fallow duration (Brandt et al. 2016) points to the long-term positive effects of FMNR for reversing land degradation (Reij et al. 2009), with significant positive livelihood impacts (Binam et al. 2015).

Social structure

Agropastoral household livelihoods rely on natural resources and non-timber forest products that extend far beyond individual fields to encompass entire “terroirs” (Bassett et al. 2007), that is, territories associated with, and controlled by, lineages or village communities governed by traditional systems of land and tree tenure. Local communities typically include the people who first settled the area, who have the right to allocate land and natural resources, and more recent migrants or late-comers of the same or different ethnic groups, who do not. Access rights to land and trees are separate, and there can be multiple and overlapping rights to individual trees.

Men usually have customary ownership of the trees on their land. Women rely to a greater extent on the tree resources located in fallows and woodland/bush areas, where access is traditionally open to all. The rights of access to fruits and other tree products are weaker for migrants. This makes the resource use rights of women and recent migrants more vulnerable to village-level or regional trends affecting land use than men’s. Increased integration in the market economy and the commercialization of tree products has resulted in increased competition for resources and the privatization of access rights. With greater restrictions, there is a real risk of widening the inequality in access to natural resources between social groups (Gausset et al. 2005; Rousseau et al. 2017).

In West African agrarian societies, farm households are made up of overlapping but semi-autonomous production and consumption units connected through labour, food and/or income-pooling arrangements. In the common, extended (polygamous) family model, the household includes individuals who farm a communal field under the jurisdiction of the household head, and who eat from the same cooking pot. The household may include 20 to 30 members or more.

The eldest male allocates cultivation rights to his wives and married sons for private fields that they manage on their own. They must also contribute their labour to the communal fields that he manages. Wives and married sons are entitled to the production from their private fields. Food produced on a woman’s field is used to supplement her own and her children’s consumption during the dry period, after cereal harvests from cooperative fields are exhausted. This production is a critical element of the household’s survival. It may also be sold to generate cash for paying school fees and purchasing clothing, medical supplies and condiments to accompany the staple cereals. Women are semi-autonomous producers and consumers, but they may not share the same production priorities as male household heads and other members of the household. Understanding this is central when designing targeted gender and food security interventions in the Sahelo-Sudanian belt. Nuclear family patterns are more generalized in the other three regions.

Income

Annual rainfall patterns result in a strong seasonality of resource availability and household activity. In the dry season household activities are focused on food processing, crafts, housework (cooking, and fetching firewood and water) and off-farm activities. In the rainy season, farming and animal husbandry require the highest levels of physical activity and energy expenditure, while nutritional intake from the previous season’s dwindling grain supplies is at its lowest. This leads to a seasonal energy deficit and a lower health

status at this time of the year. The rainy season is the time of low cash availability and high expenditure, when farmers often contract loans. The food and cash income generated by women during this period is crucial to ensuring the household's health during a period where labour is greatly needed.

In southeastern Niger, crop production generates 40–60 per cent of household income, the rest being livestock products including goats, sheep and chickens, as well as off-farm activities (Abdoulaye and Sanders 2006). In northern Burkina Faso, crop harvests meet only a few months of household food needs and are complemented by pastoralism and off-farm income from employment in development projects, gardening, small-scale commerce and seasonal migration (Nielssen 2009). An emerging source of livelihood in southern Africa is artisanal mining (gold, diamonds, chrome) whose proceeds are used to purchase household essentials including livestock supplementary feed and other agro-inputs. Migrant remittances from South Africa and to some degree from Europe have become a major source of finance for household consumption and investment, as well as for communities and governments in countries such as Zimbabwe, Zambia and Mozambique.

While poverty prevails in the agropastoral system, there are large disparities in terms of vulnerability to food insecurity in a typical village community. Livestock has become the greatest determinant of wealth, and its ownership can be even more unequal than land (Table 4.2) (Diakité 2013). However, women and children are not excluded from livestock ownership or management.

Environmental resources including various products from trees, fuelwood and grass for fodder and thatching are of far greater significance to the income of poorer households (Pouliot 2012). Also, women tend to rely on these agroforestry products to a higher

Table 4.2 Hausa household socioeconomic groups in the south-central zone of Tessaoua department, Niger

<i>Household wealth level</i>	<i>Percentage of households</i>	<i>Household size</i>	<i>Cultivated area</i>	<i>Livestock assets</i>	<i>Ownership of draught animals and carts</i>
Very poor	36	7	0.8	0–1 small ruminants through kiyo*, 2 chickens	–
Poor	28	7	1.5	2 small ruminants + 1 through kiyo*, 3 chickens	0–1 borrowed ox
Middle resource level	21	10	4	3 cattle (1–2 cows for reproduction), 11 small ruminants, 9 chickens	ox 1 cart
High resource level	15	15	7	10 cattle (5 cows for reproduction), 25 small ruminants, 15 chickens	bulls, 1 donkey, 1–2 carts, 0–1 horse

*Local system by which well-off households loan a small ruminant to poorer households. The recipient takes care of the female ruminant and in exchange is allowed to keep one out of three or four offspring. The kiyo system allows poor households to acquire an animal which they would otherwise not be able to afford, whereas the owner's animal is maintained for free.

degree than men (Pouliot and Treue 2013). Households rely on agroforestry products both for subsistence and sale for income. Agroforestry products have an important safety net function, particularly when the family is experiencing shocks, including the illness or death of a productive household member, or loss of crops or other assets.

Drought-related food deficits are a fairly frequent challenge for many families in the agropastoral system. Generally, their initial responses involve foregoing some forms of consumption and engaging in more intensive dry-season income-generating activities. When food insecurity intensifies, the household resorts to selling livestock, borrowing from merchants, selling domestic assets and selling land. Finally, if these responses fail, the family may resort to permanent emigration.

Managing risk

Families in semi-arid environments have many prospective strategies for optimizing their resource management and minimizing their risks. Farmers diversify their crop enterprises and combine crop, tree and livestock enterprises. They may carry out staggered plantings to deal with the erratic establishment of the rainy season and the occurrence of dry spells. Or they may plant larger areas to compensate for plant mortality and low yields per hectare. Crop rotation is not a common practice, but exceptions occur such as groundnut-millet/sorghum rotations in West Africa. The intercropping of cereals and legumes is more frequently used to maximize the combined yields of two or more crops or to benefit from crop interactions (N fixation, root decay, shade, reduced pest prevalence). To minimize their financial risks they often forego investment in purchased inputs such as fertilizers. Slash and burn to control weeds and a limited form of shifting cultivation are only practised in low population areas, for example Mozambique and Zambia, and also in southern Ethiopia, as justified by bush encroachment in bimodal and subtropical bioclimates.

Farmer networks allow for the reciprocal exchange of seeds and money between the farm, the village and the city in good and adverse years. In southern Africa, strategies to deal with unreliable rainfall include in-field and off-field water harvesting, growing drought-tolerant crops or varieties, intercropping and reducing the plant population to reduce the water demand by crops.

Farmers develop soil and crop management strategies at the scales of both the whole landholding and individual fields in order to overcome major production constraints, such as poor and unreliable moisture availability, low soil fertility and labour bottlenecks. In West Africa, different cropping patterns and frequencies of cultivation are often observed in concentric rings of distance around a typical farmer's household compound (Laube 2007 cited in Callo-Concha et al. 2012). The most intensive management is applied to home gardens and the crop fields that are located closest to the village or scattered farms. Management intensity is reduced in bush fields more distant from the village.

Farmers vary their management practices by crop, variety, the probability of livestock damage among their fields, and the variation in soil fertility and topography that they observe across their fields in order to reduce rainfall-related risk. When excessive rainfall and flooding occurs, sorghum plots on heavier lowland soils with high moisture retention perform poorly, while millet will tend to produce well under these conditions on the lighter soils of slopes and plateaus. The opposite case holds in late season drought.

Livestock and cropping interactions

Households in this farming system typically integrate food or cash crops with a pastoral-type of livestock production. Farmer types include herders involved in agriculture in the drier part of the system, mixed crop-livestock farmers traditionally with close arrangements with mobile herders (transhumant pastoralists) and, in wetter environments, farmers that maintain a livestock component for animal traction and milk production and open their areas to transhumant pastoralists for grazing their animals early in the dry season and again early during the wet season. In the farming system, livestock, rangeland and cropland productivities are closely linked. However, as opposed to other crop-livestock systems the fact that no forage crop or meadows are cultivated presents a challenge to maintaining livestock productivity.

Livestock provide food and income (milk and meat), soil fertility inputs (manure), and draught power for field activities, crop processing and transport. They are also a self-reproducing asset that can be built up as a source of savings and store of wealth. Cash from livestock sales is invested into purchased farm inputs including fertilizer, seed, water pumps and veterinary inputs to improve farm productivity. They are also sold to purchase food and to satisfy other needs during difficult times, and to meet social and religious obligations (Powell et al. 2004). In southern and eastern Africa, cattle are the dominant livestock, although donkeys and small ruminants (goats, sheep) become more important in the driest areas (Figure 4.3). In places affected by long cycles of drought, there has been a shift from cattle to small ruminants, as they are less costly, better adapted to drought, easier to feed and they reproduce faster than cattle (Mortimore and Adams 2001).

Figure 4.3 Supplementary dry season feeding of velvet bean and maize while the animals are still mostly grazing communal pastures. Due to shortage of dry season feed and protein availability in diets forage crops are widely adopted in this area where they are promoted. The farmer is a leading innovator selling animals to invest in feed and water source development.

Source: Sabine Homann-Kee Tui.

Goats are kept primarily for their meat and resale value, and only secondarily for their milk. In south central Niger they are the only species owned in significant numbers by women. In southern Africa women are traditionally allowed to sell goats and sheep when the need arises, without seeking permission from their husbands or male household heads. Poultry production is an increasingly important source of income throughout the system.

Livestock is grazed on open access areas during the rainy season and on arable fields during the dry season. In drought years, large numbers of livestock die, as farmers tend to resist selling before the feed supply runs out. Females especially are kept as long as possible to conserve the reproductive capacity of the herd. Within-country movement of livestock is common in drought years. For example, in Zimbabwe smallholder farmers move their cattle to higher rainfall areas with better grazing or grass supplies, with logistical support provided by government agents.

The integration of sedentary farmers and mobile herders (from both the agropastoral and pastoral farming systems) has traditionally occurred through functional links based on exchanges of grain, grazing rights, access to crop residues and water against manure. Rangelands and fallow lands provide livestock forage which transform to nutrients for cropland through manure. During the dry season livestock graze on crop residues and manure enhances soil fertility on cropland. The manure from corralling of livestock in the field greatly improves crop yields. In the Fakara region of western Niger for example, cattle provide 12–15 t/ha of manure and small ruminants provide 6–7 t/ha. This gives a residual fertility effect on crops for up to five years. However, less than 10 per cent of cropland benefits from the various types of manure application (Schlecht et al. 2004) because of the limited number of animals and duration of their stay in the village due to limited fodder resources.

Livestock mobility is a vital strategy to gain access to seasonally available forage. Seasonal herd mobility or transhumance occurs along specific routes called corridors that connect sparsely populated pasture areas with densely populated settled villages. These corridors, which include grazing areas, resting points and water points, are typically 5 to 20 m wide and facilitate livestock movements through cultivated areas. Traditionally, settled farming benefits from transhumance.

Agropastoral subsystems

There are system variants based on rainfall reliability, the importance and form of livestock production (sedentary or transhumant), the degree of interactions between farmers and pastoralists, the types of cereal and legume crops and major livestock raised, and other socioeconomic factors. Classification on a geographical basis reveals four subsystems (Table 4.3, Figure 4.1).

The Sahelian agropastoral subsystem includes the twelve countries stretching from Senegal to Sudan which have relatively similar agro-climatic conditions (located within the Sahelo-Sudanian biogeographic zone). Relative to the other regions, this subsystem is characterized by high rural poverty prevalence, a relatively high agricultural population density, very high urban population growth rate, high TLU assets per household and a fairly short access time to markets. The markets are active even though volumes traded are low and the range of services is fairly limited. Sorghum and millet occupy over 80 per cent of the subsystem's cultivated area; the goat population is 75 per cent of the whole agropastoral system's livestock. More emphasis is given to this subsystem in this chapter relative to the other three.

Table 4.3 Basic characteristics of agropastoral subsystems, 2015

<i>Subsystem characteristics</i>	<i>Northern Africa</i>	<i>Sahel</i>	<i>Eastern Africa</i>	<i>Southern Africa</i>
Total human population (million) – 2015	38.0	92.5	26.1	33.2
Agricultural population (million)	10.7	51.5	19.8	16.3
Annual urban growth from 2000 to 2015 (%)	2.4	7.7	4.4	5.0
Total system area (million ha) – 2015	25.1	148.7	66.8	202.3
Cultivated area (million ha) – 2015	8.2	40.8	9.4	9.3
Cultivated area as % of total area	33	27	14	5
Irrigated area (million ha)	0.23	0.16	0.09	1.1
Irrigated area as % of cultivated area	3	0	1	11
Total livestock population (million TLU) ^a	3.2	35.8	9.7	14.0
Major agroecological zone	Mediterranean warm/cool semi-arid	Tropical warm semi-arid	Tropical warm semi-arid/ subhumid and cool semi-arid/ subhumid	Tropical warm semi-arid/ arid
Average LGP (days)	122	119	159	129
Core LGP range (days)	75–165	90–150	115–215	55–155
Average time to 50k market (hours)	2.1	5.5	7.7	8.8
Agricultural population density (persons/total ha)	0.43	0.3	0.3	0.1
Agricultural population density (persons/cult ha)	1.3	1.3	2.1	1.8
Livestock density (TLU/total ha)	0.13	0.24	0.15	0.07
Livestock density (TLU/cult ha)	0.4	0.9	1.0	1.5
Standard farm size (cult ha/household)	4.2	4.4	2.6	3.1
Standard farm size (TLU/household)	1.6	3.8	2.7	4.7
TLU/ha	0.39	0.88	1.03	1.50
Area in sorghum (%) ^b	–	35	20	18
Area in millet (%) ^b	–	47	12	22
Area in maize (%) ^b	–	9	42	35
Area in rice (%) ^b	–	3	6	8
Area in cassava (%) ^b	–	1	6	12
Extreme rural poverty (%)	–	61	56	47

Notes: ^a 2014; ^b 2010.

Source: Refer to Table 2.4.

The East African agropastoral subsystem is less extensive and includes areas of higher LGP and rainfall patterns are mostly bimodal. A significant proportion of the subsystem is located in cool, highland agroecological zones. The subsystem also has high poverty incidence, the highest proportion of people in agriculture and the highest density of agricultural population per cultivated area. Travel time to markets is high. Maize is the dominant crop in this subsystem while sorghum and millet are less important.

The southern African subsystem stretches over a large area (similar to the Sahelian subsystem), including areas of shorter LGP. Box 4.1 presents the profile of a typical household in the subsystem. The subsystem has a lower poverty rate, the highest proportion of urban population relative to other sub-Saharan subsystems, but urbanization rates are low, because cities there are already well established. The subsystem has a low agricultural population density, a relatively long distance to market and the highest proportion of irrigated land and TLU assets per household. The main crop is maize followed by sorghum and millet.

The north African subsystem is found in Morocco, Algeria, Tunisia and Libya. It has a high proportion of land under cultivation, the highest agricultural population density and the shortest distance to market among the agropastoral subsystems. According to available data, poverty is lower (25 per cent in Morocco) than in the other agropastoral subsystems (Payne 2012). The main rainfed cereals are barley and wheat. The subsystem has a small number of cattle and a large number of sheep (23 million) relative to other subsystems, and has the lowest livestock assets per household and per hectare.

Trends and drivers of change in the system

Major trends observed in the agropastoral farming system and drivers that underpin them in seven key areas are summarized in Table 4.4 and developed in the following paragraphs.

Population, hunger and poverty

On a backdrop of environmental degradation, population growth and weakening of livelihood systems in previous decades, rural communities now live on the razor's edge with recurrent crises and chronic vulnerability. These crises are no longer caused by shocks of large magnitude like the severe droughts of the 1970s and 1980s, but by difficult episodes such as a poor cropping season that force the most vulnerable into malnutrition or sale of equipment, livestock and land assets. Household food insecurity during the hungry season and limited capacity to engage labour in the following agricultural campaign have long-term consequences on household health and production capacity (Diakit 2013). As a result, the poor and extreme poor live less and less on agriculture and make a living on daily hired labour, petty trade, livestock sales or seasonal migration. They rely on purchased cereals for at least 50 per cent of their annual calorie needs. Thus their livelihoods depend to a greater extent on cereal market prices and local availability than on agricultural production levels. The image of a self-sufficient agropastoral farmer is something of the past. In contrast, public policies are focused on increasing agricultural production and fail to benefit over half of their targets, mistakenly assuming that food insecure households depend on subsistence agriculture. They have also placed insufficient emphasis on nutritional security ensuring sufficient consumption of protein and micronutrients.

Box 4.1 A typical household in semi-arid Zimbabwe (southern African subsystem)

A typical household in this subsystem is seven persons consisting of the mother, father, four to five children and one or two members of extended family. The main crops grown are maize, sorghum, pearl millet and groundnut, under dryland farming. Maize is grown for home consumption, but the climatic conditions limit yields. The household farm is 2.5 ha, of which about 0.8 to 1.0 ha is sown to maize, 0.8 ha is sorghum, 0.5 ha millets (or 1.0 small grains), and legumes such as groundnut, bambara nut, cowpea are grown on less than 0.3 ha each or intercropped. Cotton is sometimes grown as a cash crop. Mean yields are about 500–700 kg/ha for maize (or less than 500 kg/ha in poor seasons); 200–500 kg/ha or less for sorghum, millets and legumes such as groundnuts and bambara nut. Legumes may be intercropped with maize and these will yield less than 200 kg/ha. Small vegetable gardens around the homestead are irrigated.

The household has seven to ten cattle; cattle are an important source of draught power, meat, milk and income. The neighbour owns a donkey which is also a source of draught power. The livestock graze freely on communally owned grazing land, supplemented by conserved fodder and maize stover and groundnut straws in the dry season. Cattle are dipped regularly for tick management. During the rainy season, water sources for cattle include rivers, ponds or dams, and during the dry season, boreholes and perennial rivers and wells. The household also owns twelve chickens and eight goats. This household's livestock assets make it a medium- to high-resource household.

A family member, either the son or the husband, is engaged in other non-farming activities such as brick-making. Farming is generally constrained by labour shortages and limited access to agricultural equipment, and food production is normally below per capita consumption requirements in most years. Typical household sources of income include sale of crops and livestock, sale of non-agricultural products such as bricks, casual employment, remittances and regular employment. Generally, the household earns a per capita income well below the poverty line. A typical farmer would sell a goat or chicken but not cattle to meet typical household expenditures.

Between now and 2060, the rapid pace of urbanization, which is particularly pronounced in the Sahelian subsystem (Table 4.3), and increasing disposable income in urban areas are expected to more than triple urban demand for foodstuffs, especially high value foods including dairy and meat. A major opportunity for agropastoral societies is to achieve sustained increases in adapted crop and livestock production to respond to this growing demand. Urban demand, if well connected to rural hinterlands, should stimulate intensification with appropriate access to inputs, credit, technology and markets which provide a return on investment. The precedent exists for sustained levels of food production. In 2009–2011 the weighted average contribution of imports in fifteen West and Central African countries was only 10 per cent of total caloric intake (Bricas et al. 2016). Imports peaked during the 1970s droughts, and the general trend since has been a gradual increase of both local production and imports.

Table 4.4 Summary of trends and drivers in the agropastoral farming system

<i>Drivers of farming system change</i>	<i>Trends</i>	<i>Key implications for farming system structure and function</i>
Population, hunger and poverty	Rapid population growth; urbanization; seasonal and permanent migration of male workers to cities; increased monetization of food system.	Increased demand for food; potential for stronger rural-urban linkages within and between countries. Burgeoning job demand by youth. Increased chronic household vulnerability.
Natural resources and climate	1) Increasing inter-annual and multi-year rainfall variability; 2) greening in the Sahel; 3) Increased land competition between crops and livestock; farmer-herder conflicts; decreasing rangeland area.	1) Risk-averse decision making and enterprise diversification; 2) increased system resilience; 3) change from transhumant, communal grazing and shifting cultivation to more sedentary, mixed farming activities; 4) decline in livestock productivity.
Human capital and information	1) Significantly increased access to primary and secondary education; persistent low schooling attendance of females, the rural and the poor; 2) increased sociopolitical power of young returned migrant men; 3) disadvantaged access to land and agricultural resources by women; 4) enhanced farmer access to agricultural information.	1) Variable education level in rural communities; 2) earlier access to land and livestock and village-level decision making; 3) underutilized women potential to household food security and welfare.
Energy	1) Increased use of draught power; 2) rising mechanization locally (Nigeria, Kenya, Southern Africa).	1) More efficient cultivation, transport, processing and marketing; 2) soil degradations risks.

Technology and science	<p>1) Shortening or disuse of fallows; 2) policy neglect for intensification of dry cereals; 3) lack of attention to second-generation research issues and discontinuous flow of research funding; 4) underdeveloped seed markets and weak seed certification systems; 5) time-consuming, labour-intensive cereal processing technology.</p>	<p>1) Declining density and low regeneration of fallow-dependent woody species on farmland; 2) declining soil fertility; 3) stagnant yields despite available fertilizer-responsible cultivars; 4) conclusive project experience with a combination of improved technology and marketing underutilized for driving adoption of improved technology; 5) impeded crop improvement programs and value chain development; 6) narrow availability of women for income generation and livelihood improvement.</p>
Markets and trade	<p>1) Larger domestic food markets than export markets; largest part of consumption is of local origin; 2) strong urban and rural demand for processed food products; 3) women process a high proportion of consumed foods in urban and rural areas; 4) increased poultry consumption; 5) rising number of large-scale land investments.</p>	<p>1) Domestic food demand can drive development of agricultural value chains; 2) food processing sector has high potential for growth; 3) high potential livelihood impact of improved food processing technology and quality consistency; 4) opportunity for maize substitution by sorghum/millet in chicken feed to absorb increased production and price collapses in good years; 5) capture of land and water resources with negative impact on local livelihoods and the environment.</p>
Institutions and policies	<p>1) Weakening of communal moral obligations and traditional organizations for collective work; 2) land loans challenged by long-term nature of traditional land tenure; 3) poorly functioning input and credit markets; 4) better marketing (price, season, quantities, clients) through cereal banks/warrantage systems; 5) relative policy neglect of livestock vs crops; 6) policy of cereal imports or stocks release to keep prices low in adverse production years.</p>	<p>1) Greater vulnerability to poverty traps; field labour shortages; 2) long-term investments in soil and water conservation and tree planting must be negotiated; 3) policy support required for input availability for improved technology; 4) higher farmer income and favourable technology dissemination; 5) constrained intensification of crop-livestock programs; 6) drop in farm income and disincentive to new technology adoption.</p>

An additional challenge in the agropastoral system as a whole is the large youth population who require employment. A massive, continuous flow of young adults into the job market is expected until 2050 in African subsystems due to its population structure. Agriculture is often perceived as unattractive to the youth due to the physical demands of agricultural work, low income, hindrances to new farmer establishment in accessing land and credit, and the lack of basic infrastructure (electricity, leisure activities). Yet others engage earnestly in farming enterprises when they are accessible and generate income. The Sahel has developed as a centre for international terrorist and illegal drug trafficking networks who draw recruits among the young and unemployed feeling disenfranchised and excluded as a result of a number of developments (Box 4.2).

Box 4.2 Main factors generating feelings of disenfranchisement among Sahelian youth

The role of the public school system is questioned by populations because it is poorly governed, provides insufficient professional opportunities and is seen to reproduce social inequalities. Even though it has considerably improved, access to quality education is not guaranteed for all and provides grounds to some youth for feeling excluded.

Due to the massive youth bulge and a largely informal job market, a majority of young people are un- or under-employed and cannot access independence. Public policies are poorly adapted to the reality of the largely informal Sahelian economies; employment policies focus on the educated few, reinforcing social stratification, and there is a disconnect between employment policies and technical training offered.

Religion, Islam mostly, is a strong driver for socioeconomic integration and identity-building of young people, as membership opens access to networks promoting social recognition, professional integration or mutual aid. Islamic reformist or Salafist movements have gained strength in political decision making and visibility in the public sphere by filling voids left by the State in public service delivery or conflict management. There is a major risk for Sahelian youth to adhere to Salafist currents which have become platforms for social division and political protests against the State and tradition by promoting religious intolerance or even violence, and this threatens fragile existing social and political balances.

The low conventional political representation is a major obstacle to the citizen engagement of youth. Poor governance as well as the incapacity of the State to reduce inequities, prevent food crises and provide access to services and jobs tend to breed feelings of exclusion among the youth as well as frustration and rejection towards the State. The perception of not being represented or supported by a corrupt State is a major incentive for the mobilization of youth into armed or radical groups.

International crises-related migrations, transnational (cocaine, migrants, light and heavy weapons) traffic networks and terrorism have generated insecurity and the loss of control of the State over extended areas in the Sahel. Traffic activities feed chronic insecurity, disrupt traditional human mobility and annihilate perspectives of economic and social development in some areas. Looking for economic opportunities, protest-prone, socially dissatisfied and unemployed youth are easily mobilized, indoctrinated and radicalized by extremist and jihadist groups.

Source: Arnaud 2016.

Natural resources and climate

Climate variability has a strong influence on agropastoral livelihoods. Long-term climate analyses show that inter-annual variability of rainfall in the Sahel (30 per cent average coefficient of variation) is not something recent (Figure 4.4). Intense droughts in the 1970s and 1980s have followed high rainfall periods in the 1950s and 1960s. There has also been an increasing frequency of lower-than-average rainfall since 1970 (Figure 4.4). Farmer observations suggest climatic changes including ‘false starts’ and shorter duration of rainy seasons with intervals of extreme rain or absence of it resulting in flooding or droughts, as well as temperature increase and extension of the dry cool and hot seasons (Nielssen 2009). Comparison of isohyets in the Sahel for the 1991–2009 period with average annual rainfall during the 1961–1990 period suggests a slight rainfall increase northwards.

Remote sensing work has pointed to an overall “re-greening” of the Sahelian and Sudanian belts since the late 1980s (Diouf et al. 2015; Herrmann et al. 2005) in spite of a few local exceptions either on shallow soils (Trichon et al. 2018) or due to the extensive clearing of conservation areas. This regreening trend, validated by long-term field observations, has been largely attributed to increased herbaceous production (Dardel et al. 2014) and also to an increase in woody plant cover isolated from herbaceous vegetation by considering the dry-season Normalized Difference Vegetation Index (NVDI) (Brandt et al. 2016). The increase in woody plant cover extends widely over the Sahel rangelands, the domain of the pastoral farming system (Chapter 10 this volume) (Brandt et al. 2016; Hiernaux et al. 2009) and, to a lesser extent, over Sahelian and Sudanian croplands (in practice, the agropastoral system).

The increase in vegetation production is mainly correlated with rainfall (Dardel et al. 2014). Yet its lack of geographical uniformity suggests that other factors including human-induced change are also contributing (Brandt et al. 2016). Indeed, regeneration of vast areas of previously barren agricultural land through soil and water conservation and farmer-managed natural regeneration of indigenous woody plants in cropland has been documented on large land areas in northern Burkina Faso (0.3 m ha), south-central Niger (5 m ha), Mali and other locations (Reij et al. 2009; Tougiani et al. 2009). This regreening of the region has been called the most dramatic positive environmental transformation recently seen in Africa. In Niger, institutional changes including the decline in centralized government and higher local land management autonomy have allowed local

Figure 4.4 Variability of annual rainfall compared with average in the Sahel between 1900 and 2010. Source: Nicholson et al. (2018).

farmers, supported by external technical advice and development coalitions, to rediscover tree management and disseminate its knowledge widely (Sendzimir et al. 2011). Trees and coppiced shrubs in crop fields provide improved nutrient cycling and other environmental services (Diakhaté et al. 2016). The large range of benefits reported by farmers include increased crop yields, increased availability of tree browse and shelter for livestock, income from tree products, attitudinal change and increased social capital among communities and partners, all of which have strengthened the resilience of local farming systems.

These traditionally specialized forms of agricultural and livestock production are in transition. A number of changes linked to increasing human and livestock populations and climate variability have taken place in the crop-livestock systems (Ickowicz et al. 2012). Changes include an increase in crop area, including a northward shift into traditionally pastoral areas, and changes in sowing and harvesting dates and crop species. There has been a decrease in rangeland area in comparison to the cropped area and seasonal inaccessibility due to cropping fragmentation and encroachment into pastoral zones. Transhumance is vulnerable to corridor blocks and the loss of pastures around encampment and water points due to encroachment by agriculture. Because rangeland availability has declined, herds tend to be more mobile in the dry season. Transhumant movements now extend over longer distances and for longer durations to find adequate forage resources. Conflicts with sedentary farmers in the southern part of the range have become more frequent due to competition for water and pasture resources.

At the same time livestock husbandry by some pastoralists has become more settled, and it increasingly diversifies into crop production activities and other income sources. Numbers of grazing cattle have decreased, but sedentary draught and fattened cattle and small ruminants have increased. The declining land area per person with growing population density results in a contraction of land in fallow; extensive cropping systems thus tend to integrate livestock as an alternative to maintain soil fertility. As a result, livestock management practices based on transhumance and communal grazing, and cropping systems based on shifting cultivation, are progressively evolving towards sedentarization of transhumant farm families and mixed crop-livestock farming (Powell et al. 2004). Crop-livestock interactions continue to involve both agriculturalists and pastoralists but increasingly take place within closely integrated mixed farms. Because of the lack of fodder crop the number of animals possibly raised within a farm is limited and depends on more mobile reproductive herds for maintenance.

Energy

Fuelwood is the main source of domestic energy of virtually all households in rural areas and about half of them in urban settings. High population growth, high fuelwood consumption and an increased scarcity of biomass put pressure on the remaining vegetation and tree resources. Urban-based wood cutters can conflict with rural governance arrangements over local, more sustainable use of forest resources. Expansion of gas and electricity in urban and rural areas, currently at early stages, will help to reduce pressure on forest resources.

There has been slow progress in electrification within the farming system. But many countries and international organizations have equipped themselves with energy strategies and policies. Several large-scale initiatives are focusing on the development in grid-connected and off-grid solar energy across the Sahel and other African subregions. Their

goal is to supply power to millions of people and to reduce the cutting of trees for fuel by energy-poor households.

Mini grids which harness energy from available solar, wind, hydro and biomass hold great promise for electrifying remote areas in sub-Saharan Africa. Household access to electricity offers possibilities to extend one's work hours, improve income and sometimes reduce health disorders (sore eyes, coughs, etc.) when fuels are used for illumination.

Increased adoption of animal traction has allowed an increase in the cultivated area in the agropastoral farming system, generated income that is reinvested in agricultural enterprises and the allocation of saved time to other endeavours.

Human capital and information

Access to primary and secondary education has increased significantly in the past fifty years in this farming system in general and in Sahelian countries specifically, with a schooling rate of 10 per cent in 1960 increasing to 60 per cent in 2011. Progress in education has also been significant on a gender basis. Both the girls' schooling rate and especially their school life span have significantly increased in West African countries (Arnaud 2016). Despite these advances education levels in females, and in rural, regional and poor socio-economic groups, remain lower. Education is also challenged by the increasing annual number of children growing to school age, and the quality of education has declined leading to variable but generally low basic literacy rates. There are social reasons for gender inequalities. Often the boys' educational and professional needs have precedence over the girls' right to education. Early marriages, pregnancies and domestic obligations also deny schooling to girls.

Seasonal labour migration may give young men increased social and political power as well as confidence in agropastoral communities (Nielssen 2009), with skills and experience acquired during interactions with development projects, government authorities and traders. Traditionally, and before the droughts, fathers would pay the bride price for pre-arranged marriages with their young sons from grain and livestock sales. As a result of drought and climate variability, successful young men would raise this expense by selling their labour in coastal cities for about half of the year. This could provide them with greater freedom to choose their wives, get married earlier and reach the status of household head that entitles them to receive their share of family land and livestock as well as gain access to political decisions at village level. In more recent years, chances for highly successful seasonal migration may have lessened.

A major gender gap in the agropastoral system concerns customary access to land, the most basic production factor. In some places women are lent private plots of land to cultivate. Often plots are very small and of poor land quality and/or distant from the household, or they can be relocated on an annual basis thus precluding land improvements. In many places women do not have access to private land at all (Sanders and Shapiro 2006). Usually women do not inherit individual land rights, yet there are exceptions such as the Hausa in Niger (Hughes 2014). Not surprisingly crop yields in women's fields are generally lower and female-headed households cover less of basic household expenses through primary farm production than men's (Barbedette 2013). In addition, time spent obtaining fuelwood, fetching water, pounding grain and carrying out other manual tasks constrain women's labour availability.

The fact that the farm is managed as an extended family group entity and not as a nuclear family enterprise is important when programs are aimed at developing strategies

for the farm through the household head or when they attempt to target women specifically. Gender gaps also apply in the provision of extension services, financial services and technology (FAO 2011). When donor programs have attempted to improve markets for the agricultural products of women, they have often resulted in men taking over these activities (Sanders and Shapiro 2006). In the context of increased household vulnerability and men's seasonal migration patterns, women play a larger economic role through direct contributions to household income (Diakit 2013). This may help them benefit more from agricultural services.

There is some evidence that the gender gap in African agricultural sciences is closing. Between 2000 and 2008, the female population of professional staff in 125 agricultural research and higher education agencies in fifteen countries in sub-Saharan Africa Agricultural Science and Technology Indicators sample agencies grew by 8 per cent per year on average. This is four times higher than the comparable rate of increase for the male population. However, female participation remained higher in east and southern African countries than in West Africa (Beintema and Di Marcantonio 2010).

Technology and science

As a result of population pressure in much of the farming system, the number of years that land is fallowed or rested after a cultivation period has considerably shortened or the practice has been discontinued altogether. In densely populated rural areas such as Sobaka, southern Burkina Faso, 65 per cent of farmers no longer fallow due to the unavailability of arable lands (Kabor et al. 2012). Periods when agricultural land is rested allow cropping land recovery and the growth of herbaceous grazing resources and, also, the natural regeneration and maturation of woody plants that provide a range of benefits such as soil fertility restoration, browsing resources and non-timber forest products. Over cycles of alternating cultivation and fallow, farmers selectively nurture these woody plants to develop thriving, well-stocked agroforestry parklands. Through this traditional practice, farmers have been 'spontaneously' reaping multiple benefits and ecosystem services. Without farmers' technical understanding of alternative practices to maintaining soil fertility, the trend away from alternating fallow and cultivation cycles towards permanent cultivation threatens these critical services.

As a result, young trees are absent, tree densities are declining and parkland tree populations are ageing, which affects their sustainability and the environmental services they provide. This trend pertains to a wide number of parkland tree species deliberately protected by local farmers and is particularly felt for shea (*Vitellaria paradoxa*) that can dominate local tree populations in the most active shea market supply zones of the Sudanian belt. The species occurs in twenty-one countries with an estimated potential population of 1.8 billion trees in the Sahelian subsystem (Naughton et al. 2015). Shea nuts and butter provide up to 12 per cent of total household income value and 32 per cent of total cash income for women belonging to the poorest households in Burkina Faso (Pouliot 2012) and Benin, respectively (Droy et al. 2014). Like many indigenous tree species, shea is traditionally not planted because of cultural norms, land and tree tenure intricacies and its long reproductive cycle. The disappearance of fallows as a traditional tree regeneration mechanism raises concerns for the sustainability of the resource and expected production gaps in view of the rising demand in cosmetic and confectionary shea markets (Boffa 2015).

Because of substantial investment and political support for research and market development, agricultural intensification in African drylands has been successful for cash crops

including cotton and maize. With active introduction of improved cultivars, hybrids and chemical fertilizers supported by international research centres, yields of maize in West Africa often concentrated in higher rainfall regions have doubled. Initially cotton production was also intensified with the use of animal traction and organic and mineral fertilizer and was stimulated by access to fertilizer credit, a guaranteed cotton price and non-farm income (Aune and Bationo 2008). Since the late 2000s, however, soil fertility decline, stagnating yields and low international prices due to increased outputs from large Bt cotton-producing countries has made West African cotton production less profitable, especially outside the prime production regions.

In contrast, production increases for sorghum and millet have mostly taken place through area expansion. Stagnant yields since the late 1990s reflect a policy neglect for these crops despite the existence of improved varieties and management techniques that can double or triple average yields (see also section on system performance in this chapter) (Kaminski et al. 2013). Adoption of successful technologies on a significant scale remains a challenge.

African soils are well known to be deficient in N and P. The cost of fertilizers is high. Therefore in recent decades, much effort has been spent in looking for low input management practices to treat nutrient deficiency (e.g. rotation and N fixation in cereal-legume systems) that reduce costs to farmers. However, little of these new technology developments has left the research station and gone onto farmers' fields. According to Schlecht et al. (2006), lack of capital is not a primary constraint because even adoption of low-cost technologies is low in the Sahel. Rather the profitability of technologies as well as the perceived risks (related to drought, pest attacks and price variability) appear to govern farmers' adoption of new technology. Sanders et al. (2018) argue that raising N and P levels in soils is essential to yield increases as long as ways can be found to pay for these inputs. The essential concern should not be about reducing input use but about ensuring profitable product prices and marketing margins.

Recommending inorganic fertilization along with fertilizer-responsive cultivars is well accepted for "cash crops" such as cotton and maize where yield gaps have been at least partially filled. In contrast, this approach runs counter to the conventional wisdom for sorghum and millet seen as subsistence crops, which often says that (1) these crops do not respond to inorganic fertilizer, or if they do, fertilizer is not profitable, (2) farmers will not use fertilizer on these crops even if there were agronomic and economic responses and (3) banks will not lend to farmers for sorghum and millet fertilizer. However, project evidence provides grounds for overcoming this defeatist narrative. New fertilizer-responsive millet and sorghum cultivars are available as a result of substantial research investment since the great droughts of 1968–1973 in the Sahel. Results of an INTSORTMIL field research program over the period 2004–2016 show that new technologies are profitable when implemented along with improved marketing (Box 4.4 later in this chapter).

Another important reason for low technology adoption is the lack of attention to second-generation R&D issues that address bottlenecks in the production-marketing-consumption chain, preventing large-scale adoption (Sanders et al. 2018). The case of the Malian-bred Grinkan sorghum variety illustrates this case (Box 4.3). One of the reasons why second-generation problems do not become research and/or extension issues is linked to the current funding structure of national research and extension agencies. Most of NARS funding is sufficient to cover little more than staff costs, and managers and scientists are busy looking for the next donor opportunity to support operational budgets. In turn, donors are often more interested in addressing new problems than continuing the program of a previous funder.

Box 4.3 Second-generation research-extension issues in sorghum technology introduction in Mali

Grinkan is an open-pollinated cross between Guineas (local, open head, low yield potential) and Caudatums (compact head, high yield potential) sorghum races identified in the early 1990s offering 50 to 100 per cent yield increases (1.5 to 2 or 3 t/ha) with moderate fertilization. People like its taste and the stover is highly palatable for livestock. Based on excellent pilot phase performance, a USAID-funded scaling-up program was successful in incorporating bank lending and developing contracts between farmers' associations and wholesalers. However, after extensive dissemination, women reported that "to", the daily staple prepared with Grinkan was not as sticky as with traditional processing methods. The combination of the poor "to" quality, the difficulty of renewing the seed and obtaining the recommended fertilizer led to substantial technology erosion leading to disillusionment with Grinkan. This is a chronic problem in moving from pilot to scaling up projects. However, in some villages the women started to adapt their processing method to avoid the lack of stickiness of the "to". By not soaking the grain overnight or by not separating the bran, they resolved the consistency problem. Some training was provided on these techniques by the extension service. Hence, the food consistency problem became more of a communication issue than a technical barrier to Grinkan introduction. A video showing how to resolve the processing problem as well as interviews with a wholesaler interested in selling uniform, clean Grinkan in major markets and active certified producers of Grinkan seed was also produced and shown to farmer groups and on TV. The question remains whether the recovery of Grinkan will take place. Other issues identified for accelerating the introduction of Grinkan include known insect control technologies, public policies for functioning seed and fertilizer markets, and institutional development of farmer organizations. Investing research and extension resources to build upon these first-generation successes and continue the diffusion of these new cultivars is likely to more efficiently lead to impact than starting over again with new problems.

Source: Sanders et al. 2018.

Competition of uses of a limited resource can also limit technology adoption. For example, the use of crop residues as natural pastures during the dry season and for human needs (compost, burning for potassium, containers, house material) reduces the quantity of available materials for soil mulching (Figure 4.5). Yet grazing reduces crop residue inputs to the soil to a limited extent only. The intake capacity of grazing ruminant livestock is limited to 20 per cent at most of the stover mass (and millet stems are hardly grazed at all), the remainder is trampled and turned to soil organic matter. Then about half of the intake is recycled through faeces and urine deposition (Hiernaux pers. com.). Also, problems related to land tenure rights and the lack of agricultural equipment prevent long-term investment in land improvement.

Creating a thriving seed production sector is critical to sustaining crop improvement programs and developing sorghum and millet value chains. Currently seed markets are generally underdeveloped as most farmers use their own seeds or rely on friends or neighbours, and few certified seeds are available in local markets. In Mali certified seeds are produced by the national seed service and multiplication is done by contracted farmers and seed producer

Figure 4.5 With communal access arrangements there is increasing privatization of crop residues for feed. Local by-laws determine the date when fields need to be open for communal grazing. Farmers who intend to save crop residues have to store them away from livestock access, for instance on stover platforms.

Source: Sabine Homann-Kee Tui.

groups, and certified seed is supplied to farmers through farmers' associations, development organizations and extension services (Kaminski et al. 2013). Seed renewal is important for maintaining high yields in the scaling up of new technology based on improved cultivars and associated fertilizer recommendations. But seed certification procedures involved in field verification and laboratory analysis are considered too lengthy and expensive, contributing to low demand and supply of certified seeds (Sanders et al. 2016).

A low proportion of sorghum and millet produced is still commercially processed or marketed. Agroprocessing by small and medium enterprises, many of which are run by women, is gradually developing in capital and provincial cities. Commercial processing is, in most cases, geared towards production of animal feeds, grit, malt and meal (Rohrbach 2004). Many cereal products are fermented, and they are produced by artisanal processors with uncontrolled fermentation processes. Most processing methods are laborious, manual and entirely performed by women. A low degree of cleanliness, heterogeneity in grains and unstable/insufficient quality are three common constraints in the quality of sorghum and millet raw material (Kaminski et al. 2013).

Markets and trade

Food consumption trends

While livestock production in the agropastoral system has long been market-oriented, this feature is more recent for its crop component. Regional markets of food products have

expanded with growing populations. A recent study in fifteen West and Central African countries reveals that domestic food markets are now significantly larger in economic value than export markets, including countries which are major agricultural product exporters such as Côte d'Ivoire and Cameroon (Bricas et al. 2016). Thus, domestic food demand represents a strong potential engine for the development of local agriculture, reducing the historical dichotomy between export cash crops and staple crops.

In economic value the proportion of carbohydrate-rich commodities (cereals, roots and tubers, plantains) produced locally ranges from 30 to 90 per cent of national consumption according to country, the rest being imported, while it is 80 percent for animal products and at least two-thirds for sauce ingredients and sugar-based items. Overall, national or regional products represent about 80 per cent of national food consumption, except for Senegal and Mauritania which have historically relied more on international markets. Therefore for the most part local agricultural production feeds the population in the region.

Demand for processed products

Urban populations make up a large and rapidly growing portion of domestic demand for food. There consumption by a nascent middle class of rapidly cooked, prepared foods of consistent quality available throughout the year and the consumption of food and meals outside the home are increasing (Grandval et al. 2012). This is a stimulus to the food processing sector in these countries. The diversity of local processed products available on local markets has expanded to include flours, semolina, grits, fermented pastes, oils, pre-cut meat, dried and smoked products, drinks, and the quality of these products has increased. Nevertheless, the demand for food from rural areas should not be underestimated. Rural populations are also growing and this demand makes up close to half of domestic food markets on average; on average over half of rural household consumption per capita in West and Central Africa is purchased (Bricas et al. 2016).

The agroprocessing sector operated by micro-, small- and medium-sized enterprises, which are mostly led by women, is little known and under-recognized by national governments. Yet it represents at least 25 per cent of national food consumption value and close to 30 per cent of urban food markets (Bricas et al. 2016).

Development of secondary markets for sorghum and millet

As diet quality improves in middle-income countries, cereal consumption stabilizes and the intake of protein (meat, milk, cheese), and fruits and vegetables increases. The diet shift with higher income has increased the demand for poultry rather than large livestock. This has accompanied the long-term relative price decline of poultry relative to other meats as producers become more adept at poultry technologies and as feed is produced at a lower cost with faster growth.

As the demand for cereal-based feeds has accelerated, middle-income countries generally have had to import feeds from developed countries because they could not respond fast enough. This trend applies similarly across higher-income Sahelian countries. There is rapid growth of intensive poultry production for broilers in Mali and Burkina Faso. Poultry is changing from a food of the rich and special occasions to a middle-class and even lower-class staple. This suggests a need to increase cereal productivity in order to limit feed imports. There is an opportunity to increase the use of sorghum for animal feeds. The price of maize has been increasing since 2008. New tannin-free sorghum

cultivars have 95 to 97 per cent of the feed efficiency of maize (Tandiang et al. 2014). Sorghum is associated with similar or superior chicken growth and egg production when replacing maize by up to 50 per cent in rations (Issa et al. 2015; Mohamed et al. 2015). Therefore substitution of maize by sorghum in poultry feed can be widely recommended and is already observed in Senegal and Mali (Sanders, pers. obs). Five major feed mixers have been established in Senegal, and a shift to sorghum is expected when the price becomes lower than maize. Widespread adoption of technology in cereals will affect prices. The development of such secondary markets for sorghum and millet can help reduce or avoid the price collapses farmers face during good rainfall and abundant production years (Baquedano et al. 2010).

There is potential for greater exports of sorghum and millet between surplus and deficit areas within the West Africa region, but cereal trade is constrained by high transaction costs, risks and uncertainty. Transport and logistics costs and inefficiencies, including corruption and roadway checkpoint delays, represent a large part of final market prices. These costs are driven by inadequate farm logistics and market logistics equipment and processes, as well as expensive and inefficient transport services. In addition to these high transportation and transaction costs, regional integration is hampered by inconsistencies in trade policies (e.g. export bans for self-sufficiency in food security staples that deter remuneration to local farmers) and non-tariff trade barriers (Kaminski et al. 2013).

Another concern relates to the potential detriment of large-scale land redistribution through land-grabbing processes. Recorded large-scale land investments for biofuel and food crops in West Africa (thirteen countries) alone amount to over 5 million ha (Land Matrix, 2018). Large-scale land acquisitions are often seen by governments as an injection of development capital. However, they equate to a capture of land and water resources which local populations depend upon for their livelihoods without formally owning them. Recent evidence suggests that very few such international land investments improve agricultural productivity and rural livelihoods. Rather, they are detrimental to food security, incomes, livelihoods of local people and the environment (HLPE, 2011).

Institutions and policies

The expansion of the capitalist economy since the nineteenth century has tended to weaken the mutual self-help and charitable measures characteristic of the traditional “moral economy” of village social structures in the Sahel. Traditionally, there were stronger charitable obligations within the community, stronger patron–client ties, and the state government was more sensitive to coping with drought than were the colonial governments. Because households facing hardship could turn to local notables and rely more strongly on communal moral obligations, they were less likely to fall into poverty traps.

In southern Africa migration from rural to urban and mining areas has seriously constrained labour availability in rural areas. Consequently, community activities traditionally shared in well-organized groups such as ploughing for households without draught animals, ferrying manure by households who produce large amounts and weeding fields of traditional leaders are no longer practised. In the 1980s, a national policy attempted to substitute traditional organizations with a modern village association in southern and central Mali. However, although still in existence, this association is now a non-functional entity. Presently, traditional organizations have become weak, and collective efforts for accomplishing agricultural work are difficult to organize. This is a major contributor to current agricultural field labour shortages.

However, the decentralization processes that have been established in most Sahelian countries since the 1990s generally aim to integrate the different land users with local organizations to better manage land and natural resources (Ickowicz et al. 2012). They aim to strengthen the social relationships that have supported land, forage and organic matter management, including livestock lending, common social organization for water, pastures and soil fertility management, employment for herd or crop management, and marketing organization.

Traditional land tenure has been evolving with demographic trends and increasing land scarcity; the lack of tenure security can be a constraint to agricultural intensification. Land is typically acquired either through inheritance or allocated by the traditional earth priest. In addition, there is an active system of both short- and long-term loans of land between households. A common source of conflict is the return of former residents of the village seeking to re-establish prior claims to land that is being cultivated by others. Informal arrangements between landowners and land borrowers may be called into question when long-term investments such as soil and water conservation are made. They often lead to outright eviction when trees, which are seen as a long-term claim to the land and create separate access rights to the land, are planted by farmers on loaned land.

Poorly functioning input and credit markets are a general constraint. Their low efficiency is linked to high transaction costs, repayment problems due to asymmetric information and low technical support. Any improved cultivar scaling-up program will need to interact with public policy makers who make decisions on fertilizer subsidies and availability at national level so that fertilizer recommendations are properly followed (Sanders et al. 2016). Extension services and rural infrastructure investments such as roads, electricity as well as market information services have generally been weakened following the state retreat in the aftermath of structural adjustments. However, some microfinance institutions have stepped in to help farmers open bank accounts, secure savings and access input or equipment credit.

Cereal banks are another effective approach for facilitating farmers' access to credit and leveraging higher farmer income, which has been promoted among farmer associations. Farmer associations obtain inventory credit (i.e. warrantage) for inputs and other investments from a lender by depositing grain in community storage facilities. Managers monitor market prices, quality of stored products and market supply to determine the best time and price to release the stocks onto the market. More remunerative prices are secured as associations are able to avoid sales during post-harvest price collapse or to sell later in poor rainfall years when seasonal price increases are largest and increase the supply of clean sorghum with a price premium (Box 4.4). They amass and sell larger quantities at higher levels of the marketing chain, avoiding the need for local or other intermediate marketing persons. Associations are instrumental for the rapid diffusion of technology innovations, as farmers are more likely to imitate the behaviour of successful neighbours in the association than to believe outside recommendations (Sanders et al. 2018).

Government policies have tended to be lopsided in favour of crops, to the detriment of strategies and programs focused on livestock. In past decades the focus was inappropriately placed on sedentary livestock production; it limited participation and ignored the needs and rights of pastoralists. This has significantly changed since (Chapter 10 this volume). The compartmentalization of crop and livestock development support programs is a constraint to intensification of crop-livestock programs. Governments also intervene by importing or releasing stocks of cereals in adverse rainfall years when cereal yields are low in order to drive food prices down (Abdoulaye

and Sanders 2006). This leads to a drop in farm-level income and is a disincentive to the adoption of new technology. The current level of the West African Economic and Monetary Union (UEMOA) import taxes is among the lowest in the world, and prices of exported crops are not protected (Nubukpo 2011) so that West African states were not able to shelter regional rural populations from the volatility of commodity markets in the food crises in the 2000s.

System performance

This section considers the performance of the agropastoral farming system in terms of productivity and sustainability.

Productivity

System productivity varies according to component crops and interactions among a range of factors. In West Africa, high-potential crop varieties, chemical fertilizers and pesticides, and mechanization have been widely applied in irrigated farming and to cash crops such as cotton, rice, maize and bi-annually rotated groundnut and cereals. In the eastern and southern agropastoral subsystems, improved maize cultivars and hybrids, the use of inorganic fertilizer and more recently the extensive use of fertilizer subsidies have increased yield and production in maize. To some extent this is also the case in the higher rainfall Sudanian regions endowed with better soils, where maize is commonly grown with the use of inputs. In contrast, yields for sorghum and millet have remained stagnant overall, and there is a very large yield gap between common non-manured on-farm (350–600 kg/ha) and research experiment yields (1.5–2 tons/ha). Thus there is a substantial potential to close the sorghum yield gap on farmers' fields.

It is widely believed that increased land productivity in the agropastoral system can be obtained through the use of external inputs, including inorganic fertilizers. Indeed where rainfall is higher than 300 mm, the factor most limiting to crop production is nutrients and not water. In the Sahel region, especially in the southern part, net primary production is limited by low N and P availability (Penning de Vries and Djitéye 1982). Aune and Bationo (2008) emphasize that organic and mineral soil fertilization is a necessary entry point for agricultural intensification in the Sahel, because introduced technologies such as improved varieties or water harvesting either have little impact or are not economically feasible (Figure 4.6). Appropriate soil fertility management can therefore be considered fundamental for developing sustainable agriculture in the drylands of West Africa. However, the efficiency of N and P fertilizers is undermined by rainfall variability and depends on the level of land degradation. Yet in the majority of poor fertility soils in the Sahel, N and P fertilizer helps adaptation to irregular rainfall distribution by boosting growth, especially that of the root system. On degraded soils and in dry and irregular climatic conditions fertilizer application can be unprofitable and risky for dryland farmers. Affordability is often a constraint to resource-poor farmers.

Soil conservation and water harvesting with rock bunds, tied ridges, grass strips, half-moons and planting pits (zai) allow the restoration of crop production in degraded lands. Expected yield increases from these technologies alone are low (200 kg ha⁻¹ of sorghum grain); they increase with manure (700 kg ha⁻¹) or mineral fertilizer (1400 kg ha⁻¹), but the largest crop yield increases are obtained when zai is associated with both of them (1700 kg ha⁻¹) (Reij et al. 1996). Similar results were obtained in Zimbabwe with tied-ridging

Figure 4.6 Dwarf SV2 sorghum variety grown on farm released by the Zimbabwean Government Small Grains Breeding Program in close collaboration with ICRISAT and widely found in Southern Africa. Due to various agronomic challenges and moisture stress, grain yields are about 500 kg/ha.

Source: Ronald Tirivavi.

and combined fertilizer treatments (Nyamangara and Nyagumbo 2010). Phosphorus deficiency is a major constraint to crop production for rainfed crops in West Africa – and the response to N is substantial only when both moisture and phosphorus are not limiting. Potassium (K) is usually not a problem but continuous exploitation without K fertilizer can lead to K deficiency.

Agricultural research since the late 1990s has indicated that crop rotation and intercropping should be used to improve soil fertility and nutrient availability to crops (when purchased inputs cannot be used). N use efficiency can be increased through rotation of cereals with legumes and through the optimization of planting density. Long-term rotation trials conducted in West Africa have clearly demonstrated substantial yield benefit (Bagayoko et al. 2000; Bationo et al. 2011).

The use of locally available African phosphate rock has been advocated as a cheaper alternative to imported water-soluble P fertilizers for subsistence farmers in semi-arid zones. While the potential of rock phosphate was claimed to be large, for instance in combination with cereal/legume rotations, its effectiveness (solubility and availability to crops) depends on its chemical and mineralogical composition (Lompo et al. 2018). Other barriers to use include its slow solubility, its dust and the need for acidulation, an industrial process for which Sahelian countries may not have a comparative advantage; their experience to date has not been conclusive.

Fertilizer micro-dosing or the application of small doses of fertilizer in the hill of the target grain crop at planting provides a quick start to the plant and an earlier finish, thus avoiding both early-season and end-of-season droughts, and increases crop yields by 50 per cent (Tabo et al. 2005). Because of the reduced investment cost compared with broadcasting over the whole field, micro-dosing is affordable to the poor. A micro-dosing instrument adapted to donkey and bovine animal traction that reduces labour investment from 30 h/ha to 3.25 h/ha has been experimentally developed. In the AGRA project, 40,000 of the targeted 130,000 households in Burkina Faso have adopted the micro-dosing technology and applied it in 40 per cent of the cultivated area in the project zone. Efforts are underway to further scale up and scale out the technology to wider areas (Gnanou 2013).

Organic amendment, crop rotation and fallow can be used to improve organic carbon in soils. Substantial yield increase has been achieved by using 2 to 4 tons of crop residues. Crop residue application decreases wind and water erosion. It also improves root growth, phosphorus availability, potassium nutrition and increases soil pH (Koulibaly et al. 2016). However, despite its promising effects in the Sahel and elsewhere, adoption of crop residue biomass for mulch is generally insufficient given its other uses such as construction material and grazing (Figure 4.7). Though as mentioned earlier grazing also promotes mineralization of crop residue nutrients through trampling and excrements.

Yield increases from improved sorghum varieties can also be expected, subject to the use of both micro-dose fertilization and soil and water conservation techniques (e.g. 1400 kg/ha compared to 800 kg/ha for local varieties; Ouattara et al. 2018).

Figure 4.7 Cattle grazing maize stover near homestead, Nkayi district, Zimbabwe.

Source: Sabine Homann-Kee Tui.

Sustainability

The protection, improvement and restoration of agroecosystems including soil fertility and water availability are key elements of sustainability. They also provide food security, income generation over time and environmental service provision (biodiversity, and climate change adaptation and mitigation). Given the increased population, demand for natural resources and change from traditional practices, the sustainability of the integrated crop-livestock system, which has in ancient times produced enough food to feed people, is now in question.

The variety of soil and water conservation techniques and achievements previously outlined are important for improving water and nutrient management in the medium to long term. However, sustainability of the agropastoral system relies on the maintenance of woody perennials in agriculture. Due to the deeper soil layers tree roots are able to reach, associating trees on farm expands the system's nutrient and water cycles compared to purely annual cropping. Trees improve soil organic matter content, enhance soil porosity and water retention capacity resulting in improved soil fertility and crop yields. Water table recharge is also promoted. The capacity of communities to regenerate tree cover in degraded farmland through farmer-managed natural regeneration is key to restoring sustainable rural livelihoods. The primary benefits claimed by farmers practising FMNR are increased assets in terms of tree stocks and healthy livestock from being able to feed on reliable leaf and grass fodder reserves, both of which increase household resilience (Weston et al. 2015). There is also an increased availability of wild resources including fruits and leaves for human consumption as well as construction material which can be sold to generate income. Rural households gain mental wellbeing from the greener landscape as well as positive attitudes towards environmental management and increased social capital from collective FMNR action. Overall the livelihood impact per household in terms of social, health, environmental and economic values generated through FMNR were estimated at US\$655–887 per year (Weston et al. 2015). Given that land restoration has been implemented over large areas, this indicates the high potential for scaling up these benefits and enhancing system sustainability. In Niger 300,000 ha of degraded land has been treated with soil and water conservation (Reij and Smaling 2008). Similarly, SWC is practised on at least 200,000 ha of degraded land on the Central Plateau of Burkina Faso and on an estimated 5 million ha in Zinder, Maradi and the adjacent parts of the Tahoua Region, in southern Niger (Reij et al. 2009).

But growing more is not enough. Farmers also need to receive prices that sustain their livelihoods. Linking increased crop production with enhanced market uptake is key to stimulating the wider adoption of improved land management technologies and making self-sufficient food production more sustainable. The development of effective input/output markets and the provision of accessible and affordable credit facilities are necessary ingredients of this strategy.

Another key factor of sustainable farm performance is the capacity for the household head to maintain positive relations and cooperation with household members as well as for the household to invest in social capital with members of the village community. The former affects decision-making processes regarding production choices, the sharing of roles and responsibilities in farm work, the containment of household expenditures, and education/training decisions regarding children. The latter is instrumental for ensuring adequate access to land resources, especially for farmers who do not originate locally (Barbedette 2013).

Strategic priorities for the system

The relative importance of five major pathways for livelihood improvement and poverty escape by poor households in the agropastoral system is shown in Table 4.5. Strategic priorities for the agropastoral farming system are summarized in Table 4.6 and developed in following paragraphs.

A significant potential for poverty reduction is expected through the intensification and diversification of the agropastoral system, especially among farmers who are able to organize themselves in farmer associations. The opportunity to improve system performance and reduce food insecurity derives from the large productivity gaps for both crops and livestock, and the increasing urban demand for agricultural products and qualitative improvements in diets. Intensification includes a range of interventions such as further deployment of soil and water conservation techniques, farmer-managed natural regeneration, and the optimization and intensification of crops and livestock associations (use of crop residues, manure, animal traction, cross investment). Intensification of crop-livestock associations involves increased use of inputs including fertilizer micro-dosing or moderate use of fertilizer, improved seeds, feed supplements, veterinary products and animal traction to enhance the existing farming practices (Figure 4.8).

Some parts of the farming system have nearly reached the limits of available arable land while others have not. The prospects for farm size increase are restricted overall, although traditional land allocation mechanisms allow flexibility locally. Off-farm employment either as a part-time occupation or seasonal migration is a major option for some household members to generate income and remittances that can be invested in farm enterprises. A move to non-agricultural rural and urban livelihoods is also likely to remain a significant but risky option for poor and very poor households who cannot generate sufficient income in farming. This trend needs to be supported with the diversification of rural non-agricultural activities in both upstream (provision of inputs and equipment) and downstream (processing and commercialization) sectors of value chains. Thus creating employment in micro to medium enterprises and industries should be a priority for public policies.

Population

Current public policies need to become ‘pro-poor’ and add nutritional security and social protection concerns to meet the needs and expectations of the poorest and most

Table 4.5 Relative importance of household livelihood improvement strategies

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total agric. population (2015)</i>
% of total agric. pop	—	53	47	100
Intensification	2	2	4	3
Diversification	2	1.5	2.5	2
Increased farm size	2	0.5	1	1
Off-farm employment	1	3	1.5	2
Exit from agriculture	3	3	1	2

Source: See Chapter 1, ‘Farm household decisions and strategies’ and Chapter 2, ‘Household strategies’.

Figure 4.8 Family field of velvet bean (*Mucuna* spp.) promoted for dry-season feeding of livestock, Gwanda district, Zimbabwe. While interest for *Mucuna* as a cover crop is limited, there is now a large uptake as feed with strong interest by women.

Source: Patricia Masikati.

Table 4.6 Summary of strategic interventions for the agropastoral farming system

<i>Drivers of farming system evolution</i>	<i>Strategic interventions</i>	<i>Implications for farming system structure and function</i>
Population, hunger and poverty	1) Sharpen the targeting of the poor and strengthen nutritional security and social protection in food security policies; regulate and harmonize minimum daily labour wage; 2) support free circulation of goods and people; plan economic growth programs coupling rural production areas and urban demand; 3) promote youth employment.	1) Increased food and nutritional security of the poor; 2) sustainable development and strengthened growth of domestic value chains; 3) age-balanced economic participation.
Natural resources and climate	Promote individual and collective actions at watershed scale and share lessons, including multi-stakeholder transhumant corridor management associated with grazing areas, agroforestry parkland regeneration, FMNR, soil and water conservation, groundwater-based irrigation.	Reduced resource use conflicts; increased system productivity and resilience.

Human capital, and information	<ol style="list-style-type: none"> 1) Improve access to primary education for vulnerable and excluded groups; boost farmer extension, community health; 2) promote women's access to land and reduce their domestic burdens; promote women's economic diversification; 3) ICTs for dissemination of technology and market information. 	<ol style="list-style-type: none"> 1) Socially more inclusive education; enhanced women's contribution to household livelihood; 2) increased capacity for intensification and diversification.
Energy	<ol style="list-style-type: none"> 1) Scaling up of agroforestry interventions and FMNR; strengthen local institutions for decentralized forest management; optimize crop-livestock synergies including draught animals; 2) rural electrification; 3) alternatives to firewood in urban zones. 	<ol style="list-style-type: none"> 1) Sustainable local fuelwood supply; 2) higher rural productivity; 3) lower urban demand for fuelwood.
Technology and science	<ol style="list-style-type: none"> 1) Sustainable crop and livestock intensification (active integration of on-farm trees, improved crop cultivars, agroecological options, targeted fertilization, water harvesting, certified seed production and distribution, locally and industrially produced livestock feeds, veterinary products, optimized crop-livestock synergies, etc.); diversification (poultry, small fattening schemes, dairy, reproductive herds); 2) integrate improved technology and market innovations (storage, warrantage, new markets); 3) include technology performance evaluation and the tackling of second-generation issues in research. 	<ol style="list-style-type: none"> 1) Increased system productivity and livelihood sustainability; 2) systemically planned and coordinated innovations along value chains; 3) strengthened research program continuity and efficiency over time.
Markets and trade	<ol style="list-style-type: none"> 1) Support producer integration in value chains, market development, processing, and dissemination of market and consumer information for sorghum, millet, cowpea and groundnut products; 2) diversify end products, promote product quality control, adequacy to consumer preferences and improved packaging; 3) establish regional standards and market information systems; remove regional trade barriers. 	<ol style="list-style-type: none"> 1) Increased capacity of food demand to drive agricultural sector growth; 2) strengthened value chains; 3) increased regional integration of agricultural and food markets.
Institutions and policies	<ol style="list-style-type: none"> 1) Create incentives for adoption of sorghum, millet, cowpea and groundnut technologies. Strengthen producer organizations with specialized training; 2) public-private partnerships to promote value chains; invest in connectivity and infrastructure for rural entrepreneurs; 3) develop crop insurance programs; 4) ensure access rights for pastoralists. 	<ol style="list-style-type: none"> 1) Stronger sorghum and millet value chains including improved technologies, trained producer groups, effective institutions, processed products of consistent quality; 2) lower local vulnerability to crop failure; 3) increased mobility and tenure security for pastoralists.

vulnerable to food insecurity. Given the importance of selling one's daily labour as a main livelihood source for the rural poor, initiating steps towards regulating daily labour and proposing a harmonized minimum wage would help the poorest households ensure their food security.

The free circulation of people, goods and services needs to be encouraged in rural poverty reduction strategies (Cour 2006). Issues and programs of poverty eradication and economic growth are best addressed at the scale of local, market-centred production areas by strengthening the capacity of urban and rural communities to interact rather than focusing on urban and rural areas separately. Attention to infrastructure-related transactions costs, competition patterns and market attractiveness is key to boosting farmers' capacity to respond to urban demand.

Investing in youth employment and their contribution to socioeconomic development should be a government priority. This is particularly crucial to ensure political stability in the Sahel. A new generation is needed to replace ageing household heads, and labourers are needed for agricultural field activities. Revitalizing interest for rural youth to play an active role in sustainable agriculture requires access to appropriate training, finance, land and markets, making their activity remunerative and worthwhile. Programs that promote the coupling of training systems and employment, and support the youth until they are integrated into an income-generating activity, are needed. To restore the attractiveness of the agricultural sector, youth entrepreneurship should concur with efforts to boost the economic potential of rural zones through value addition, modernization and diversification of agricultural value chains. This can occur through close linkages with and reinforced capacity of local public, private and community initiatives.

Natural resources and climate

Given the low nutrient status of soils and harsh climatic conditions, the maintenance of multipurpose trees and shrubs on farmland that utilize a larger pool of nutrients and water than annual crops is key to farmland productivity, and the sustainability and resilience of agropastoral communities.

Conserving and replenishing the resource base to enhance system production can be achieved through promoting individual and collective actions at community and watershed scales to implement erosion prevention, soil and water conservation designs, improved management of crop-livestock interactions and incorporation of agroforestry technologies. Islands of higher fertility created through this process can then generate lessons for scaling up.

To expand the benefits of FMNR, a focus is needed on encouraging optimum age distribution of tree populations and scaling up these approaches to areas with currently low tree cover. Lessons on the successes of FMNR-based restoration of degraded lands should be further documented, so they may be widely accessible to farmers and relevant sets of supporting local actors.

In order to enhance livestock mobility and reduce farmer-herder conflicts, efforts are needed to characterize and document transhumant needs that include corridors, grazing areas, water points and resting points, as well as consult all stakeholders involved. This information is important for local and national-level authorities in supporting coordinated management planning by local stakeholders whose livelihoods depend on these resources.

Human capital and information

Education and literacy are critical as the adoption of technology and the ability to exploit market opportunities are closely related to the literacy level of farm decision-makers. Investment is needed in the continued support of primary education services, especially for vulnerable and excluded communities (nomadic, displaced, low-density or gender-based groups). Educational and agricultural extension support is also needed for farm women and men. Participatory farmer training should target the entire production system including technical, market and institutional aspects integrating the management of risk.

Attention is also needed on the impact of technology innovations on women. If innovations require them to work longer on family fields, time reduction on their private fields will translate into negative livelihood impacts. Development programs need to strengthen women's bargaining power and help them receive payments for specific operations. Adapted technologies could make their activities more productive and improve their agricultural productivity, market returns and their wellbeing and that of their family. The focus of training can be directed towards economically rewarding activities such as poultry production, vegetable gardens and crafts. In order to have an impact, this needs to be accompanied by infrastructure and technology investments that help free up women's time in domestic burdens linked to improved fuelwood stoves, hauling water, procuring firewood and food processing.

When traditional land tenure keeps them from accessing land individually, women can be supported to form producer groups and request land from lineage elders or village authorities for their economic activities. Because such groups give the village a good reputation with NGOs or aid agencies, men may also benefit and tend to support such arrangements. Moreover, as the fields of the group are shared by all women, and owned and inherited by no one specifically, they do not threaten the male-dominated system in place of land tenure.

Technology and science

The rapidly increasing demand for food and for qualitative improvements in diets provide opportunities for farmers to intensify and diversify production.

Given declining fallow practices which have allowed the raising of woody plants in crop fields, new, active ways of maintaining trees during cultivation cycles are needed. For many useful, semi-domesticated species on farmland, community awareness and commercial incentives are required for the regeneration and planting of trees and their management in currently cultivated fields and for the raising of their local value through tree improvement.

A particular need for research and extension is to target innovations that reduce the large yield gaps. This can be achieved by increasing the availability of inorganic fertilizers, new cultivars and associated technologies to assist farmers, such as small-scale, low-cost irrigation schemes. The loss of fallows' soil fertility enhancement function underscores the need for fertility inputs. Fertility research and soil labs will be instrumental in generating location-specific fertilizer recommendations to increase yield and reduce production costs. Building on achievements in past decades, the breeding of improved crop cultivars with a focus on increased yields targeted for intermediate height, fertilizer responsiveness and screened for taste preferences, remains critical. Livestock management can be intensified for higher productivity according to production goal (reproduction, meat, milk) taking

into account optimal age-sex composition. As local input industries develop, greater reliance could be placed on livestock feeds and veterinary products for animal health within efficient, market-linked systems. Optimized crop-livestock synergies in terms of the use of crop residues, manure and livestock cash flows to crops are also critical for intensification. This could be part of multidimensional diversification programs that incorporate poultry, small fattening schemes, dairy and reproductive herds.

Too often, low soil fertility leads to low input use despite the fact that high returns can be reaped from increased inputs if linkages to markets are developed. Project results (Box 4.4) demonstrate that moderate input use for fertilizer-responsive sorghum and millet cultivars can be profitable and widely adopted when implemented with improved marketing (Sanders et al. 2018).

Box 4.4 An integrated market-oriented approach to scaling up intensive sorghum and millet production

The strategy of the INTSORTMIL field research program promotes new technology, improved marketing and new institutions to raise the price of products received and to reduce the costs of inputs, as well as start-up input credit (Sanders et al. 2018). New technology packages trialled include new cultivars, moderate fertilizer use, water retention techniques and improved agronomic recommendations. The package also relies on a new extension approach through farmers' associations established for participating farmers. Marketing activities are designed to complement technology introduction and respond to the price collapses that characterize cereal production in the Sahel, thus reducing expected profits and retarding increased input use. The principal price collapse is the post-harvest one as most farmers attempt to sell their harvest at the end of the season in order to meet pressing harvest time expenditures (school fees, ceremonies, labour payments, etc.). Prices also collapse in good and sometimes normal rainfall years because of oversupply to traditional markets and few alternative markets. The third price collapse is provoked by the public policy response to rapid cereal price increases in adverse rainfall years, which affects urban consumers (and rural poor) by the importing of cereal or releasing surplus stocks (Abdoulaye and Sanders 2006).

To address the main price collapse, storage and group marketing of larger quantities is encouraged through a warrantage system. Farmers' associations hold the cereals until shortly before planting and then sell, thus avoiding the annual post-harvest price collapse. This avoids the need for local or other intermediate marketing people and stores enough quantity to enable sales at a later stage in the supply chain. Assistance is provided to identify new markets, especially for processed food and livestock rations, and to increase value addition by maintaining the cereals in a clean environment and obtaining a premium price from millet food processors and sorghum-based broiler producers. Finally, developing marketing cooperatives enables farmers to create an institution that sells in bulk; systematically searches for higher prices for products and lower prices for inputs; creates a client relationship with banks to facilitate lending to farmers through the cooperative; and develops better links with markets, technology and extension institutions. Presentations and publications help convince public officials that they should not

intervene to reduce cereal prices except in the worst drought years. The long-term strategy for sustainability food production needs to include farmers making profits and investing in their operations.

The integrated strategy appears to be working well. When farmers properly follow recommendations, average farm yields of 1.5 t/ha for sorghum and 1.2 t/ha for millet are obtained in good and normal rainfall years. This is an increase from 800 to 1000 kg/ha for sorghum with traditional practices in the cotton zone, and from 400 to 700 kg/ha for millet. With marketing, price increases of 20 to 50 per cent have been obtained since the mid-2010s. This is especially important in adverse rainfall years when the new cultivar response to fertilizers is much lower. The project has shown there is good crop response to moderate levels of inorganic fertilizer and it is highly profitable for farmers.

Since the late 2000s this pilot project has also identified other buyers for millet and sorghum, beyond subsistence use, local and regional markets (Baquedano et al. 2010). The marketing strategy is especially important in adverse rainfall years; banks are presently providing credit for sorghum and millet production in Mali and Senegal. The project reached a scale of 2,000 ha in Senegal and 5,000 ha in Mali in 2011.

Source: Sanders and Ouendeba 2012.

Systematic attention needs to be given to the production and trade of sorghum and millet for value chain development. Incentives are needed to increase the supply and demand for certified seed through more rationalized and cheaper seed certification procedures. National research institutes have a key role to play in the training of farmer seed producers in large-scale testing and demonstration trials for certified seed production. Farmers' associations can participate in testing and promoting demand for certified seed. Recommended ways for this include distribution via small seed packs and seed auctions in areas of poor market infrastructure, and in more commercialized areas, involvement of agro-input dealers, shopkeepers and traders (Kaminski et al. 2013; Sanders et al. 2016).

NARS capacity to identify technologies with high immediate or downstream performance potential and respond to second-generation problems should be strengthened. Lack of NARS funding and dependence on short-lived donor support for R&D operations lead to the tendency to discard new technologies that are facing second-generation problems as the next program from another funding agency starts. Thus funding mechanisms need to be set up to allow NARS to build on research gains and respond to emerging problems, allowing for enhanced relevance of new technologies. In order to support technology introduction, NARS investment is required in the analysis of the whole farming system and performance evaluation. Here impact evaluation is not primarily used for reporting to donors, but to identify second-generation research issues and supplement the innovations attempted. Multidisciplinary teams including economists, social, agricultural and food scientists are best qualified for such evaluations (Sanders et al. 2016).

Markets and trade

Effective value chain development including marketing development, scaled-up processing and improved circulation of market and consumers' information is needed in order for domestic food demand to stimulate the local agricultural sector. There is a large potential

for domestic production of sorghum and millet as well as cowpea and groundnut to serve urban markets and the development of competitive intra-rural markets. Ways are needed for the greater integration of producers into value chains. One option is the outgrower schemes that allow participating farmers to supply established agroprocessors under contract. This can be accompanied by private-led investment in warehousing, purchasing, treatment, storage and farming extension support for cereal production.

Key sorghum and millet value chain outlets that can stimulate the processing sector include prepared food, animal feeds (poultry), malt and beer for breweries, and blended flour for pastries and restaurants. Products need to be well adapted to preferences and quality requirements of consumers, and those processed from sorghum and millet can also compete with imported rice and wheat that have gained importance in consumption in recent decades. Processing techniques, including control over the choice of ingredients, homogeneity of raw material and the use of measuring instruments, should be applied to ensure product quality consistency. Establishing regional norms and standards will contribute to high quality, safe, traceable agricultural and food products.

The artisanal food processing sector (individual, small- and medium-sized enterprises) needs increased visibility and support in national food policies and aid agency programs for several reasons. It generates employment, especially for women. It drives local agricultural development by linking rural food supply and urban demand and has transformed local staple crops into commercial crops. It also supplies food for the poorest and most food-insecure segments of the populations and can play major roles in food security and poverty reduction. An enabling environment is also needed for large-scale processing industries in key sectors.

Interventions for the removal of regional trade barriers are also needed to expand transborder trade in sorghum and millet and generate export revenue for countries. These include uniform and transparent quality certification measures, open and accessible market information (including price, supply, quality requirements and other trade requirements), better provision of extension services, and enhanced producers' capacity for group marketing. Developing regional market information systems can promote regional integration.

Farmers' organizations, especially social movements of the rural poor and civil society organizations that support them, need to be represented to ensure scrutiny and accountability of large-scale land investment processes.

Institutions and policies

The long-standing neglect towards staple crops, especially sorghum, millet and cowpea, should be reversed with an enabling policy environment and investment of relatively greater government budgets in the subsector. Appropriate market, price and credit incentives are needed to increase adoption of improved technologies by farmers and to improve yields.

Producer organizations have an important role to play in generating higher marketable surpluses, coordinating marketing strategies and stimulating farmers' participation in the market. Subsidizing investments in storage facilities will help improve marketing and better manage risk linked to supply and price variations. Marketing strategies aim to reduce between- and within-year price variability through the widespread use of inventory credit and the absorption of oversupplies in new markets of processed cereals. But this approach

for increasing farmers' revenues can be sustainable only if public policy decisions are made to reduce cereal export bans, imports and stock releases in adverse years (Abdoulaye and Sanders 2006).

The emergence of strong producer organizations for sorghum and millet with increased bargaining ability and transparency towards their members should be supported by targeted marketing and management training. Value chains can be promoted by encouraging public-private partnerships with investment and credit provision involving producer groups, finance institutions and small- and medium-sized agriprocessors using sorghum and millet (manufacturers of animal feed, processed and semi-processed food and beverage products). Demand for sorghum and millet food products should be encouraged by strengthening food quality control measures and supporting improved quality packaging.

Market-linked farming entrepreneurship needs improved connectivity of rural areas through road infrastructure, health and education services, as well as assured supplies of water, electricity and telecommunications.

In view of the current low productivity of extensive crop-livestock systems and growing urban demand for livestock products, policy orientations should favour promoting the further growth and intensification of domestic small-scale livestock production sectors rather than subsidizing imports. A continuous effort is needed to place research on crops and livestock into its integrated systems context, and cross-disciplinary linkages and cross-sectoral approaches should be supported. Peri-urban fattening and dairying operations can be developed with cut and carry feed systems and use of outputs from urban agroprocessing factories as feed supplements.

System conclusions

Given the risk-prone environment agropastoral farmers live in, maximizing probability of success and reducing risk need to be incorporated in R&D approaches. This means building the whole system capacity and adopting an integrated approach that addresses the range of constraints farmers face along the value chain.

Being the most prevalent food source in the farming system and highly adapted to local agroecological conditions, sorghum, millet and cowpea are key strategic crops for improving food security in the agropastoral system. Political will and investments can reverse the current underdevelopment of their value chains, low market penetration and level of processing in response to significant urban demand.

An integrated, crop-livestock sustainable intensification approach is recommended to boost higher productivity in the system. Low input including agroecological techniques are essential for enhancing the resilience of agropastoral systems. Their poverty reduction potential can be increased when complemented by increased input use on the condition that structural innovations for raising prices to farmers and market development are designed from the outset for raising profitability and lessening vulnerability. Successful options include improving product quality, selling later in the season, selling to higher levels of the marketing system, selling in larger quantities and using farmers' associations to assert more bargaining power.

Crop production in agropastoralism systems is no longer limited to self-sufficient subsistence for home consumption. The food system is largely monetarized and farmers are involved in other economic activities. Thus programs focused on agricultural supply should be widened to consider contributions to and dependencies on other rural development sectors.

For scaling up the benefits of system intensification in the young economies of the agropastoral system, there is a great need to invest in people, institutional and organizational strengthening, as well as information sharing and coordinating development across institutions, value chain components and sectors. Multi-stakeholder innovation platforms are promising instruments to promote this process.

References

- Abdoulaye, T. and Sanders, J.H. 2006. New technologies, marketing strategies and public policy for traditional food crops: Millet in Niger. *Agricultural Systems* 90: 272–292.
- Arnaud, C. 2016. *Jeunesses sahéliennes: dynamiques d'exclusion, moyens d'insertion*. Notes techniques no. 15 Agence Française de Développement, Paris.
- Aune, J.B. and Bationo, A. 2008. Agricultural intensification in the Sahel: The ladder approach. *Agricultural Systems* 98: 119–125.
- Bagayoko, M., Buerkert, A., Lung, G., Bationo, A. and Römhild, V. 2000. Cereal/legume rotation effects on cereal growth in Sudano-Sahelian West Africa: Crop yields, soil mineral nitrogen, vesicular arbuscular mycorrhizae and nematodes. *Plant and Soil* 218(1): 103–116.
- Bagayoko, M., Maman, N., Palé, S., Sirifi, S., Taonda, S.J.B., Traore, S. and Mason, S.C. 2011. Microdose and N and P fertilizer application rates for pearl millet in West Africa. *African Journal of Agricultural Research* 6(5): 1141–1150.
- Baqueda, F., Sanders, J.H. and Vitale, J. 2010. Increasing incomes of Malian farmers: Is elimination of U.S. subsidies the only solution? *Agricultural Systems* 103: 418–432.
- Barbedette, L. 2013. *Profil d'exploitations familiales d'éleveurs en Afrique de l'Ouest et en Afrique Centrale. Synthèse illustrée par 33 études de cas de 130 études réalisées en 2010 et 2013*. Association pour la promotion de l'élevage au Sahel et en savane dans neuf pays.
- Bassett, T., Blanc-Pamard, C. and Boutrais, J. 2007. Constructing locality: The terroir approach in West Africa. *Africa* 77(1): 104–129.
- Bationo, A., Hartemink, A., Lungu, O., Naimi, M., Okoth, P., Smaling, E. and Thiombiano, L. 2006. African soils: Their productivity and profitability of fertilizer use. *African Fertilizer Summit* 9–13 June 2006, Abuja, Nigeria.
- Bationo, J., Kimetu, B., Vanlauwe, M., Bagayoko, S., Koal, A. and Mokwunye, U. 2011. Comparative analysis of the current and potential role of legumes in integrated soil fertility management in west and central Africa. In Bationo A., Waswa B., Okeyo J.M., Maina F., Kihara J. and U. Mokwunye (eds) *Fighting Poverty in Sub-Saharan Africa: The Multiple Roles of Legumes in Integrated Soil Fertility Management*. Springer, pp. 117–150.
- Beintema, N.M. and Di Marcantonio, F. 2010. *Female Participation in African Agricultural Research and Higher Education: New Insights. Synthesis of the ASTI – Award Benchmarking Survey on Gender-Disaggregated Capacity Indicators*. IFPRI Discussion Paper 00957.
- Binam J.N., Place, F., Kalinganire, A., Hamade, S., Boureima, M., Tougiani, A., Dakouo, J., Mounkoro, B., Sanogo, D., Badji, M., Diop, M., Babou, A.B. and Haglund, E. 2015. Effects of farmer managed natural regeneration on livelihoods in semi-arid West Africa. *Environmental Economics and Policy Studies* 17: 543–575.
- Boffa, J.-M. 1999. *Agroforestry Parklands in Sub-Saharan Africa*. FAO Conservation Guide 34. FAO. www.fao.org/docrep/005/x3940e/X3940E00.htm.
- Boffa, J.-M. 2015. Opportunities and challenges in the improvement of the shea (*Vitellaria paradoxa*) resource and its management. Occasional Paper 24. World Agroforestry Centre.
- Brandt, M., Hiernaux, P., Rasmussen, K., Mbow, C., Kergoat, L., Tagesson, T., Ibrahim, Y.Z., Wélé, A., Tucker, J.C. and Fensholt, R. 2016. Assessing woody vegetation trends in Sahelian drylands using MODIS based seasonal metrics. *Remote Sensing of Environment* 183: 215–225.
- Bricas, N., Tchamda, C. and Mouton, F. 2016. *L'Afrique à la conquête de son marché alimentaire intérieur. Enseignements de dix ans d'enquêtes auprès des ménages d'Afrique de l'Ouest, du Cameroun et du Tchad*. AFD, collection études de l'AFD, no 12.

- Callo-Concha, D., Gaiser, T. and Ewert F. 2012. *Farming and Cropping Systems in the West African Sudanian Savanna. WASCAL Research Area: Northern Ghana, Southwest Burkina Faso and Northern Benin*. Working Paper Series 100. ZEF Working Paper Series, ISSN 1864-6638, University of Bonn.
- Cour, J.M. 2006. *Population Dynamics, Poverty Alleviation and Sustainable Development: A Demographic and Spatial Framework*. World Bank Consultant, France.
- Dardel, C., Kergoat, L., Hiernaux, P., Mougin, E., Grippa, M. and Tucker, C.J. 2014. Re-greening Sahel: 30 years of remote sensing data and field observations (Mali, Niger). *Remote Sensing of Environment* 140: 350–364.
- Diakhaté, S., Gueye, M., Chevallier, T., Diallo, N.H., Assigbetse, K., Masse, D., Sembène, M., Ndour, Y., Dick, R.P. and Chapuis-Lardy, L. 2016. Soil microbial functional capacity and diversity in a millet-shrub intercropping system of semi-arid Senegal. *Journal of Arid Environments* 129: 71–79.
- Diakité, M.E. 2013. Pauvreté et vulnérabilité en Afrique de l'Ouest: quelles évolutions ? *Grain de sel* (59–62): 6–8.
- Diouf, A., Brandt, M., Verger, A., Jarroudi, M., Djaby, B., Fensholt, R., Ndione, J. and Tychon, B. 2015. Fodder biomass monitoring in Sahelian rangelands using phenological metrics from FAPAR time series. *Remote Sensing of Environment* 7: 9122–9148.
- Droy, I., Pascual, C. and Bidou, J.-E. 2014. Inégalités de genre et vulnérabilité alimentaire en milieu rural béninois: des interactions complexes. In Guetat-Bernard, H. and Saussey, M. (eds) *Genre et savoirs. Pratiques et innovations rurales au Sud*. IRD éditions, coll. A travers champs, pp. 85–115.
- FAO. 2011. *The State of Food and Agriculture 2010–2011. Women in Agriculture: Closing the Gender Gap in Development*. FAO.
- FAOSTAT (undated) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- Gausset, Q., Yago-Ouattara, E.L. and Belem, B. 2005. Gender and trees in Pén, southwestern Burkina Faso: Women's needs, strategies and challenges. *Danish Journal of Geography* 105(1): 67–76.
- Gnanou, A. 2013. *Interview de Pr Taoua Sibir Jean-Baptiste: Maître assistant et chercheur à l'INERA. 2010–2018*. Réseau MARP Burkina, <http://reseaumarpbf.org/spip.php?article78&lang=fr>.
- Grandval, F., Broutin, C. and Delmas, P. 2012. Comprendre la demande des villes pour valoriser les produits locaux. *Grain de sel* 58: 5–7.
- Herrmann, S.M., Anyambab, A. and Tucker, C.J. 2005. Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change* 15: 394–404.
- Hiernaux, P., Diarra, L., Trichon, V., Mougin, E., Soumaguel, N. and Baup, F. 2009. Woody plant population dynamics in response to climate changes from 1984 to 2006 in Sahel (Gourma, Mali). *Journal of Hydrology* 375: 103–113.
- HLPE. 2011. *Land Tenure and International Investments in Agriculture*. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome 2011.
- Hughes, O. 2014. *Literature Review of Land Tenure in Niger, Burkina Faso and Mali: Context and Opportunities*. Catholic Relief Services.
- Ickowicz, A., Ancey, V., Corniaux, C., Duteurtre, G., Pocard-Chappuis, R., Touré, I., Vall, E. and Wane, A. 2012. Crop-livestock production systems in the Sahel: Increasing resilience for adaptation to climate change and preserving food security. In Meybeck A., J. Lankoski, S. Redfern, N. Azzu and V. Gitz (eds) *Building Resilience for Adaptation to Climate Change in the Agricultural Sector. Proceedings of a Joint FAO/OECD Workshop*. 23–24 April 2012, pp. 261–294.
- Issa, S., Jariel, S., Brah, N., Harouna, L. and Soumana, I. 2015. Use of sorghum on stepwise substitution of maize in broiler feeds in Niger. *Livestock Research for Rural Development* 27(10), www.lrrd.org/lrrd27/10/issa27212.html.
- Kaboré, S.A., Bastide, B., Traoré, S. and Boussim, J.I. 2012. Dynamique du karité, *Vitellaria paradoxa*, dans les systèmes agraires du Burkina Faso. *Bois et Forêts des Tropiques* 313(3): 47–59.

- Kaminski, J., Elbehri, A. and Samake, M. 2013. An assessment of sorghum and millet in Mali and implications for competitive and inclusive value chains. In A. Elbehri (ed.) *Rebuilding West Africa's Food Potential*. FAO/IFAD, pp. 479–501.
- Koulibaly B., Dakuo, D., Traore, O., Ouattara, K. and Lompo, F. 2016. Long-term effects of crops residues management on the soil chemical properties and yields in cotton–maize/sorghum rotation system in Burkina Faso. *Journal of Agriculture Research* 5(1): 706–714.
- Land Matrix. 2018. www.landmatrix.org/en/get-the-detail/by-target-region/westernafrika/?order_by=.
- Laube, W. 2007. *Changing Natural Resource Regimes in Northern Ghana. Actors, Structure and Institutions*. ZEF Development Studies. Lit Verlag Dr. W. Hopf, Vol. 4.
- Lompo, F., Bationo, A., Sedogo, M.P., Bado, V.B., Hien, V. and Badiori, O. 2018. Role of local agro-minerals in mineral fertilizer recommendations for crops: Examples of some West Africa phosphate rocks. In Bationo, A., Ngaradoun, D., Youl, S., Lompo, F. and Opoku Fening, J. (eds) *Volume 1: Improving the Profitability, Sustainability and Efficiency of Nutrients Through Site Specific Fertilizer Recommendations in West Africa Agro-Ecosystems*. Springer, pp. 157–180.
- Mohamed, A., Urge, M. and Gebeyew, K. 2015. Effects of Replacing Maize with Sorghum on Growth and Feed Efficiency of Commercial Broiler Chicken. *Journal of Veterinary Science Technology* 6: 224. doi:10.4172/2157-7579.1000224.
- Mortimore, M.J. and Adams, W.M. 2001. Farmer adaptation, change and ‘crisis’ in the Sahel. *Global Environmental Change* 11: 49–57.
- Naughton, C.C., Lovett, P.N. and Mihelcic, J.R. 2015. Land suitability modeling of shea (*Vitellaria paradoxa*) distribution across sub-Saharan Africa. *Applied Geography* 58: 217–227.
- Nicholson, S.E., Fink, A.H. and Funk, C. 2018. Assessing recovery and change in West Africa’s rainfall regime from a 161-year record. *International Journal of Climatology* 38(10): 3770–3786.
- Nielsen, J.Ø. 2009. Drought and marriage: Exploring the interconnection between climate variability and social change through a livelihood perspective. In Hastrup, K. (ed.) *The Question of Resilience: Social Responses to Climate Change*. The Royal Danish Academy of Sciences and Letters, HFM 106, pp. 159–177.
- Nubukpo, K. 2011. *L’improvisation économique en Afrique de l’ouest. Du coton au franc Cfa*. Karthala.
- Nyamangara, J. and Nyagumbo, I. 2010. Interactive effects of selected nutrient resources and tied-ridging on plant performance in a semi-arid smallholder farming environment in central Zimbabwe. *Nutrient Cycling in Agroecosystems* 88: 103–109.
- Ouattara, B., Taonda, S.J.B., Traoré, A., Sermé, I., Lompo, F., Peak, D., Sédogo, M.P. and Bationo, A. 2018. Use of a warrantage system to face rural poverty and hunger in the semi-arid area of Burkina Faso. *Journal of Development and Agricultural Economics* 10(2): 55–63.
- Payne, W.A. 2012. *The Comprehensive Inception Phase Report for CRP 1.1 – Dryland Systems. A Multidisciplinary Characterization of Dryland Systems in West Africa and Dry Savannas, North Africa and West Asia, East and South Africa, Central Asia & Caucasus and South Asia*. CGIAR Research Program on Drylands.
- Penning de Vries, F.W.T. and Djitéye, M.A. 1982. *La productivité des pâturages sahéliens: une étude des sols, des végétations et de l’exploitation de cette ressource naturelle*. Centre for Agricultural Publications and Documentation, Wageningen, 3, 20.
- Powell, J.M., Pearson, R.A. and Hiernaux, P.H. 2004. Crop–Livestock Interactions in the West African Drylands. *Agronomy Journal* 96: 469–483.
- Pouliot, M. 2012. Contribution of “women’s gold” to West African livelihoods: The case of shea (*Vitellaria paradoxa*) in Burkina Faso. *Economic Botany* 66(3) 237–248.
- Pouliot, M. and Treue, T. 2013. Rural people’s reliance on forests and the non-forest environment in West Africa: Evidence from Ghana and Burkina Faso. *World Development* 43: 180–193.
- Reij, C. and Smaling, E. 2008. Analyzing successes in agriculture and land management in Sub-Saharan Africa: Is macro-level gloom obscuring positive micro-level change? *Land Use Policy* 25: 410–420.
- Reij, C., Scoones, I. and Toulmin, C. 1996. *Sustaining the Soil: Indigenous Soil and Water Conservation in Africa*. Earthscan.

- Reij, C., Tappan, G. and Smale, M. 2009. *Agroenvironmental Transformation in the Sahel: Another Kind of "Green Revolution"*. IFPRI Discussion Paper 00914. International Food Policy Research Institute, Washington, DC.
- Rohrbach, D.D. 2004. Improving the commercial viability of sorghum and pearl millet in Africa. Unpublished.
- Rousseau, K., Gautier, D. and Wardell, A. 2017. Renegotiating access to shea trees in Burkina Faso: Challenging power relationships associated with demographic shifts and globalized trade. *Journal of Agrarian Change* 17(3): 497–517.
- Sanders, J.H. and Ouendeba, B. 2012. Intensive production of millet and sorghum for evolving markets in the Sahel. Unpublished.
- Sanders, J.H., Ouendeba, B., Ndoye, A. and Témé, N. 2018. Developing new technologies and market strategies for sorghum producers in developing countries: The Sahel case. In Rooney, B. (ed.) *Achieving Sustainable Cultivation of Sorghum, Volume 2, Sorghum Utilization Around the World*. Burleigh Dodds Science Publishing Limited.
- Sanders, J. H., Ouendeba, B., Ndoye, A., Teme, N and Traore, S. 2019. Economics of increasing sorghum productivity in Sub-Saharan Africa: The Mali case. In Zhao Z.-Y. and Dalhberg J. (eds) *Sorghum: Methods and Protocols, Methods in Molecular Biology*, vol. 1931, pp. 223–243. Springer Science+Business Media, LLC, part of Springer Nature.
- Sanders, J.H. and Shapiro, B. 2006. Policies and market development to accelerate technological change in the semi-arid zones: A focus on Sub-Saharan Africa. In Peterson, G.A., Unger, P.W. and Payne, W.A. (eds) *Dryland Agriculture*, second edition, Agronomy Monograph no. 23, pp. 879–900. American Society of Agronomy.
- Schlecht, E., Buerkert, M., Tielkes, E. and Bationo, A. 2006. A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems* 76: 109–136.
- Schlecht, E., Hiernaux, P., Achard, F. and Turner, M.D. 2004. Livestock related nutrient budgets within village territories in western Niger. *Nutrient Cycling in Agroecosystems* 68: 199–211.
- Sendzimir, J., Reij, C.P. and Magnuszewski, P. 2011. Rebuilding resilience in the Sahel: Regreening in the Maradi and Zinder regions of Niger. *Ecology and Society* 16(3): 1.
- Tabo, R., Bationo, A., Diallo Maimouna, K., Kassane, O. and Koala, S. 2005. *Fertilizer Microdosing for the Prosperity of Small Scale Farmers in the Sahel: Final Report*. International Crop Research Institute for the Semi-arid Tropics (ICRISAT), Sadore, Niger.
- Tandiang, D.M., Diop, M.T., Dieng, A., Yoda, G.M.L., Cisse, N. and Nassim, M. 2014. Effect of corn substitution by sorghum grain with low tannin content on broilers production: Animal performance, nutrient digestibility and carcass characteristics. *International Journal of Poultry Science* 13(10): 568–574.
- Tougiani, A., Guero, C. and Rinaudo, T. 2009. Community mobilisation for improved livelihoods through tree crop management in Niger. *GeoJournal* 74: 377–389.
- Trichon, V., Hiernaux, P., Walcker, R. and Mougin, E. 2018. The persistent decline of patterned woody vegetation: The tiger bush in the context of the regional Sahel greening trend. *Global Change Biology* 24: 2633–2648.
- Weston, P., Hong, R., Kaboré, C. and Kull, C.A. 2015. Farmer-managed natural regeneration enhances rural livelihoods in dryland West Africa. *Environmental Management* 55(6): 1402–1417.

5 The highland perennial farming system

Sustainable intensification and the limits of farm size

John Lynam

Key messages

- Endowed with high agroecological potential, the highland perennial farming system makes a large contribution to the economy and food security of East African countries despite its limited geographic area.
- With declining farm size and the discontinuation of fallowing resulting from demographic pressure, the system's opportunities for intensification, income growth and livelihood diversification are largely defined by its integration into national markets.
- Government and private sector investors will need to target sustainable intensification and rural poverty reduction interventions to the specific needs of each subsystem.
- Specialization in higher value cash crops for growing domestic urban markets in the commercializing subsystems of central Kenya and northern Tanzania needs to be complemented with the development of efficient food staple markets. Poorer households should be helped to obtain higher wage off-farm employment through investments in education and credit programmes to support enterprise development in value chain activities.
- Support for diversifying systems in the Albertine Rift, southern Tanzania and western Kenya needs to promote commercialization of higher value cash crops, horticulture and smallholder dairy while improving staple food crop productivity through improved soil fertility management practices, strengthening of agronomic research, the development of fertilizer markets and stronger regional market integration.
- The development of stagnating systems of southern Ethiopia should associate short-term safety net programmes, medium-term farming system productivity interventions and longer-term investments in road infrastructure, education and family planning.

Summary

The highland perennial farming system enjoys a highly favourable agroecology in a mountainous terrain. The farming system is based on a diverse range of crops that exploit ecological niches in this terrain and is anchored by perennial crops, particularly East African

highland bananas, coffee and agroforestry, which minimize soil disturbance in such sloping terrains. Cattle are also an integral part of the system, with a recent shift to higher value dairy animals and a corresponding increase in forage production. These ecologies are limited in geographic extent, and rural population growth has been a principal driver of declining farm size and the development of permanent cultivation. Average rural population density is the highest in rainfed Africa, and average farm size in many parts of the East African highlands has fallen to a critical threshold that no longer supports purely agricultural livelihoods. The density of poor households is the highest on the continent.

The liberalization of agricultural markets in the 1990s has released the other principal constraint, namely market integration. Where market infrastructure is sufficiently well developed, the highland perennial farming system has raised incomes through diversification into higher value cash crops, particularly horticulture, smallholder dairy, high quality coffee and smallholder tea. However, such market-led intensification has not been universal and has depended on integration into national markets. Central Kenya and northern Tanzania have been the principal beneficiaries, while western Kenya, southern Tanzania and the Albertine Rift are only beginning such diversification pathways. Southern Ethiopia has the highest population densities and is the least integrated into national markets. Technical change supports the market development process and is limited where markets remain underdeveloped. Due to critically small farm sizes, increasing participation in a growing rural non-farm economy and reliance on remittances from migration of some household members are expected. The highland perennial farming system thus has the potential to be the most productive system and at the same time the largest source of rural-urban migration in East Africa.

Introduction

The highland perennial farming system has, because of its unique ecology, played a larger role in the agricultural economies of African countries than its limited geographical scope might suggest. The highlands, essentially located in East Africa, have long growing periods so that agriculture is not usually water limited, and often have relatively fertile soils of volcanic origin – other soils particularly in the Albertine Rift, are relatively infertile being of granitic origin. Also, these areas were relatively free of mosquito-borne human diseases and were often the areas that were first settled. The highlands thus now have some of the highest rural population densities in sub-Saharan Africa and some of the highest agricultural potential, as this ecology is suitable for crops such as horticulture, floriculture, coffee and tea, as well as for dairy, given lower disease pressures on cattle.

The highland perennial farming system has been a natural experiment on the interactions between population growth, access to land and common property resources and the intensification of farming, particularly in terms of soil fertility management. Expanding urban markets and the liberalization of markets in the late 1990s offer a critical driver for further intensification of this farming system. Thus, this chapter is primarily framed around the concept of market-led intensification in the highland perennial system, and a range of conditions affecting market development.

Overview of the farming system and subsystems

The system comprises six spatially separate subsystems reflecting the heterogeneous topography in East Africa (Figure 5.1). These are located in the highlands of southern

Tanzania, Mt Meru and Mt Kilimanjaro region of northern Tanzania, the humid highlands of southwestern Ethiopia, the central highlands of Kenya around Mt Kenya, the western highlands of Kenya including Mt Elgon (and extending into Uganda), and the Albertine Rift including eastern Democratic Republic of Congo (DRC), Rwanda, Burundi, southwestern Uganda and the Kagera region of Tanzania. All subsystems are based on perennials but have very different market contexts, which offer a comparative framework in terms of system drivers and farmer strategies. Table 5.1 gives the aggregate data for the system, and the significant heterogeneity in subsystems is described later. This comparative framework will group subsystems depending on market context. The first part of this section describes the agroecology and structure of the farming system in terms of crop and livestock activities. The subsequent section focuses on population–farm size interactions, with mention of proximity/access to markets. A later section elaborates market influences.

This farming system has evolved in the context of rolling to steep topography and very sharp ecological gradients. These create many specialized and intensive production niches that allow cereals from rice to wheat and teff to be grown, and the production of a range of root and tuber crops from cassava to potatoes, as well as horticultural crops, tree crops

Figure 5.1 Map of the highland perennial farming subsystems.

Sources: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Table 5.1 Basic system data (2015): highland perennial farming system

Data item	Data
Total human population (million)	82.5
Agricultural population (million)	61.0
Total system area (million ha)	39.3
Cultivated area (million ha; % of total area)	8.0; 20
Irrigated area (million ha; % of cultivated area)	0.77; 10
Total livestock population (million TLU)	20.2
Main agroecological zone	Tropical cool subhumid
Length of growing period (average, days; core range, days)	267; 240–330
Access to services (low/medium/high)	Medium-high
Distance to 50k market (average, hours; core range, hours)	5.6; 2–10
Agricultural population density (persons/total area; persons/cultivated area)	1.6; 7.7
Livestock density (TLU/total ha; TLU/cultivated area)	0.51; 2.5
Standard farm and herd size (cult ha/household; TLU/household)	0.7; 1.8
Extreme poverty (% of rural pop)	51

Source: Refer to Table 2.4.

and livestock. All of these are allocated spatially across multiple plots, which range from converted wetlands to marginal hillsides and managed as part of a diversified risk management strategy. The temporal allocation of crops varies from the bimodal rainfall patterns around the equator to the more unimodal patterns of southern Ethiopia and southern Tanzania. Highland perennial systems in general are highly diversified, but the staple food crop, which anchors the farming system and provides the household subsistence requirements, varies depending on the agricultural history and the level of market integration of the subsystem.

The East African highland banana (EAHB) (*Musa acuminata*) is the basic staple in most of the highland perennial farming system. In other areas it is a principal secondary staple. Although *Musa* is of Asian origin, EAHB has a secondary centre of diversity in the East African highlands. EAHB is well adapted to highland topography. The plants are grown in continuous, closed canopy. They are mulched and much of the organic matter is recycled through the system. The soil is not disturbed, except for the occasional intercropping with beans, and some banana groves have persisted for over a century. EAHB were selected for their relatively high starch content, and the countries of the Albertine Rift have the highest per capita consumption of bananas in the world. Both culturally and in terms of ecological adaptation, EAHB have contributed to the sustainability of these permanently cultivated systems. However, with an increase in nutrient exports from the system, declining soil fertility leads to opening of the canopy, increased leaching of soil nutrients, and enhanced susceptibility to pests and diseases.

Ensete, another genus of banana, occurs in wild forms above 1200 metres. Enset was domesticated in Ethiopia and is primarily grown and consumed in that country. The corm (bulb) and pseudostem provide starch-based products that form the staple food in the highlands of southwestern Ethiopia. As with EAHB, enset contributes to the sustainability of the farming system in areas of quite high population density through continuous vegetation cover, nutrient cycling and minimal soil disturbance. Cattle are an integral part of these systems and provide the manure that has improved the soil structure compared with

uncultivated soils. Such consistent improvement in soil fertility and structure through manure and crop residue management also characterizes the EAHB system of the Kagera region in Tanzania (Baijukya et al. 2005). In both areas a loss of grazing with expansion in cultivated area and declining cattle manure are putting pressure on soil fertility and system sustainability.

In Kenya, maize was promoted as a smallholder cash crop from the period following World War I, although often in competition with European producers. Similarly, in Tanzania maize was promoted by colonial administrations in the interwar years. While EAHB remains the principal staple in the home gardens on Mt Meru and Mt Kilimanjaro's upper slopes, maize and to a limited extent rice has expanded onto the lower slopes. In the southern Tanzanian subsystem, maize and beans have been the principal staples, certainly since independence. Maize cultivation associated with the distribution of hybrid maize and subsidized fertilizer was further intensified with the villagization programme in 1974–76. At the same time, rice has expanded in cultivated, wetland areas.

Coffee became the major cash crop in the region following World War I, with the establishment of Departments of Agriculture and the development of coffee buying points which led to the initial shift of the farming system in East Africa towards a greater market orientation. Arabica coffee was domesticated in Ethiopia and exports go back to the opening of the Franco–Ethiopian highway. Even today, coffee accounts for around 60 per cent of the country's foreign exchange earnings.

Subsystems¹

The overall highland perennial system is in many ways defined by high rural population density and the associated decline of average farm size, although variations are found across subsystems. Southern Ethiopia is the most densely populated subsystem and land-labour ratios are about a quarter of what they are in the southern highlands of Tanzania, the least densely populated subsystem. Arable land per rural resident has been declining rapidly in several countries, particularly Ethiopia and Kenya (Table 5.2)

Table 5.2 Hectares of arable land per person in agriculture (ten-year average) in selected countries

	1960–69	1970–79	1980–89	1990–99	2000–09	2000–09 land- person ratio as % of 1960–69
Ethiopia	0.501	0.444	0.333	0.224	0.218	43.5
Zambia	0.643	0.607	0.398	0.342	0.297	46.2
Kenya	0.462	0.364	0.305	0.264	0.219	47.4
Uganda	0.655	0.569	0.509	0.416	0.349	53.3
Tanzania	0.546	0.493	0.452	0.375	0.330	60.4
Malawi	0.480	0.446	0.357	0.304	0.307	64.0
Zimbabwe	0.613	0.550	0.452	0.420	0.469	76.5
Rwanda	0.212	0.213	0.195	0.186	0.174	82.1
Mozambique	0.356	0.337	0.320	0.314	0.294	82.6
Ghana	0.646	0.559	0.508	0.492	0.565	87.5
Nigeria	0.982	0.860	0.756	0.769	0.898	91.4

Source: FAOSTAT (2010).

Table 5.3 Arable land per person in the six highland perennial subsystems

<i>Subsystems</i>	<i>Ha/person</i>
Southern Ethiopia	0.036
Albertine Rift	0.130
Northern Tanzania	0.074
Southern Tanzania	0.136
Central Kenya	0.046
Western Kenya	0.073

where it has reached strikingly low levels (Table 5.3). Average national land-labour ratios in East Africa are well below those of most other African countries, and in the highlands reach levels only typical of the populous areas of Asia, which tend to be irrigated or with high rainfall.

The following section characterizes differences between the highland perennial subsystems based on the influence of topography, population, farm size, development history and market context. A later section will show how markets influence development pathways to further differentiate subsystems.

The highland subsystems of western Kenya and central Kenya

Roughly 40 per cent of Kenya's rural population lives on 5 per cent of its arable land, and 3 per cent of the population controls 20 per cent of the nation's arable land (Jayne et al. 2012: 13). The highest rural population densities in Kenya are in the highland perennial system, and Vihiga has the highest on the continent at over 1,000 persons per km².

Average farm size is 1.2 ha in the central highlands and 0.97 ha in the western highlands (Kibaara et al. 2008). This is less than half the average for Kenyan smallholders (2.3 ha). Mean farm size, however, obscures that most farms are significantly smaller than 1 ha, and in districts like Vihiga modal farm size is around 0.5 ha. Allan (1965) considered an appropriate farm size in the Kikuyu highlands to be 2.4 ha, which would allow an integrated crop-livestock system with a crop and grass ley rotation. Probably the farm-size threshold that is most critical for sustainable production in the highland perennial system is that which allows integration of a dairy cow. Farm sizes of less than 0.4 ha are probably reaching this threshold, as well as the threshold to maintain food security (Waithaka et al. 2006).

The western highlands tend to have a higher population density and less developed market infrastructure than the central highlands. The former region is much further from the principal market, Nairobi, and as Waithaka et al. (2006: 248) note, "Market access is a more important factor than population density in determining differences between central and western Kenya in dairy and crop production". The result is a significant difference in income levels and poverty rates between the central and western highlands. Western Kenya has the highest density of rural poor in Kenya, exceeding 200 per km² and more than 60 per cent of the population lives below the national poverty line (CBS 2003). In central Kenya the density of rural poor is still relatively high at around 100 per km², but poverty rates tend to be less than 30 per cent.

Farming system structure in the two areas is quite similar: both areas have a higher number of crops (14) than other regions, and the western highlands has the highest index of crop and agricultural diversification, followed closely by the central highlands (Kimenju and Tschirley 2008). Maize is the principal staple crop, supplemented by bananas, root

crops and small grain cereals. However, there are major differences between the two areas in the management, performance and sustainability of the farming system. In 2007, farms in the western highlands allocated 42 per cent of the cropped area to maize (down from 53 per cent in 2004), 8 per cent to tea and 20 per cent to coffee, compared with the central Highlands with 35 per cent maize, 17 per cent tea and 17 per cent coffee. In the central highlands farmers had diversified much more into higher value crops. Although farmers in both subsystems allocated about a quarter of their cropped land to horticultural crops, this tended to be root crops in the west and higher-value French beans, onions and tomatoes in the central highlands (Kimenju and Tschirley 2008).

Possibly the largest change in the Kenyan highlands has been the integration of intensive livestock into the farming system, as shown in Table 5.4 for the central highlands. As farm size has declined, there has been a progressive shift towards dairy under zero grazing systems. The highlands have also moved to higher value, dairy breeding stock, and dairy production has virtually transformed from an industry based on large-scale production to reliance on small-scale producers. This has been most dramatic in the central highlands, where 95 per cent of cattle are improved breeds and 22 per cent of cropped area is devoted to fodder crops. In the western highlands, on the other hand, 67 per cent of cows are improved and only 11 per cent of cropped area is in fodder crops (Kimenju and Tschirley 2008). Animal nutrition is much more constrained in the western highlands, relying predominately on maize stover with significantly lower nutritive value.

The highland subsystems of southern and northern Tanzania

The subsystems on Mt Meru and Mt Kilimanjaro in northern Tanzania are stratified by the very sharp altitude and therefore ecological gradient. On Kilimanjaro, human settlement is concentrated in the zone between 1000 and 1800 metres and has existed there for an estimated 1,900 years. Over time, agriculture evolved into what has become known as the Chagga home gardens (Winter 2009). The gardens, one of the first examples of permanent systems in Africa, are multi-storey and based on EAHB. Banana plants are cultivated below high shading trees, coffee bushes below the banana plants, pulses below the coffee bushes, and vegetables and root crops below the pulses (Winter 2009). The system depends on stall-fed livestock for manure to fertilize the gardens, and may include traditional irrigation. The system is structurally similar to the rainforest from which it was

Table 5.4 Changes in grazing systems for smallholder dairy production between 1977 and 1996 in Kiambu district within the Kenyan highlands

<i>Year of survey</i>	<i>Farm size (ha)</i>	<i>Households (%) by grazing system</i>		
		<i>Free</i>	<i>Semi zero</i>	<i>Zero</i>
1977	2.9	65	13	25
1992	1.9	33	19	48
1996	1.1	28	5	67

Source: Bebe 2003.

Notes: Free grazing tends to occur on communal lands. Zero-grazing implies animals are staff fed on cut and carried fodder, predominantly from farm land. The mix of the two practices is referred to as semi zero-grazing.

derived and has an extraordinarily high level of biodiversity, estimated at over 500 plant species, of which 400 are not cultivated (Hemp and Hemp 2009).

Average farm size in the northern highlands is the lowest in Tanzania, at just above 1 ha (Minot 2010). The home garden ecology has been fully exploited, and to maintain subsistence needs under declining farm size, households have opened plots lower down in the savanna ecology, with a focus on maize production and rice where irrigation of rice is possible. These lower plots are more extensively cultivated. A higher percentage of smallholders in Kilimanjaro use organic fertilizers (primarily animal manure), improved varieties (just over 60 per cent) and chemical inputs including fertilizer (just over 80 per cent) than any other region in Tanzania (Anderson and Gugerty 2012). Because the region is relatively well integrated into markets, with relatively good access to both the Nairobi and Dar es Salaam markets, and because of the favourable, agroecological production niches and access to irrigation, there has been a shift in cash cropping from coffee to horticulture, in some cases for international export. Adaptation thus has involved both expansion into less productive ecologies and a shift to more highly profitable cash crops. For these reasons, poverty rates remain the lowest in the country, even with the relatively small farm sizes.

The southern highlands subsystem, on the other hand, has larger farm sizes, lower population density, greater constraints on access to markets and less diverse systems, although with significant spatial variation in cropping activities and livelihood patterns (FEWS-NET 2008). Large areas are still under forest reserves, and there are also large-scale tea and coffee plantations. Cropping activities vary by altitude and positioning within the sloping topography, with inherent soil fertility increasing towards lower parts of the slope and being highest in the bottom lands. The dominant shift, however, has been from a reliance on EAHB and maintenance of terraces from the colonial period before ‘villagization’ in 1974–76 to much heavier reliance on maize production. Moving individual households into villages increased the time required to attend to plots, especially in terms of manure management, and shifted the comparative advantage towards annuals, especially in the more remote, extensive fields, and away from perennial crops. This was reinforced by expanded adoption of ox cultivation on flatter areas, hybrid maize and chemical fertilizer. However, although the southern region has the highest rate of inorganic fertilizer use (34 per cent) in Tanzania (Anderson and Gugerty 2012), fertilizer use still remains low; residues are burned, and there has been a resulting overall decline in soil productivity (Majule 2010). With increasing investment in roads there has been an increase in horticulture production near to these roads, but overall, the southern region has become the major supplier of cereal grain to the Tanzania market, in effect becoming its bread basket.

The onset subsystem of southwest Ethiopia

The onset-coffee subsystem of southwest Ethiopia also has a multi-storey structure similar to the Chagga home gardens, with a high level of crop diversity. Abede et al. (2010) identified 78 crop species cultivated in the home gardens of Sidama. The ecological complementarity of the two key crops is matched by livelihood complementarity in terms of meeting both cash and subsistence needs. Livestock, particularly cattle and small ruminants, are also a key component of the system, providing draught power, meat, milk and manure, even on these relatively small farms (FEWS-NET 2006).

Average farm size in this Southern Nations, Nationalities, and People’s (SNNP) region (at less than half a hectare) is the lowest in Ethiopia, and by extension the lowest

Table 5.5 Farm size distribution in the Ethiopian highlands by region, 2011–12

Panel A – Nationally representative statistics from the Central Statistical Agency (2012)

	<i>Oromia</i>	<i>SNNP</i>	<i>Amhara</i>	<i>Tigray</i>	<i>Ethiopia</i>
Average farm size (ha)	1.15	0.49	1.09	0.91	0.96
Farm size inequality – Gini coeff.	0.43	0.44	0.41	0.43	0.46
Percent with less than 0.5 ha	30.0	61.7	33.4	41.4	9.7
Total number of holders (millions)	5.46	3.39	4.00	0.96	14.29

Panel B – Agricultural Growth Programme Survey (AGPS) statistics

<i>Variables/ region</i>	<i>Oromia</i>	<i>SNNP</i>	<i>Amhara</i>	<i>Tigray</i>	<i>Ethiopia</i>
Average cultivated area (ha)	1.32	0.93	1.37	1.56	1.46
Percent with less than 0.5 ha	18	35	22	17	23
Number of holders (millions)	4.15	2.38	2.54	0.28	9.36

Source: Headey et al. 2013.

Notes: Panels A and B are derived from two different statistical sources. Gini coefficient is the standard economic measure of inequality within the range 0–1.

across the East African highlands (Table 5.5). Over 60 per cent of the farms are less than half a hectare in size. Unlike the Kilimanjaro region, there are no adjacent agroecologies in which to expand cultivated area without permanent migration, leaving only system intensification or livelihood diversification as strategies to absorb the continuing growth in population in this region.

The East African Highland banana subsystem of the Albertine Rift

Although coffee and EAHB are the principal crop components in the subsystem of the Albertine Rift, there is a mosaic of other crops depending on agroecology, primarily altitude, topographical position and soil type. The Albertine Rift encompasses Rwanda, Burundi, the Eastern Congo highlands, southwest Uganda and the Bukoba area of Tanzania. Since the 1930s and 1940s, this region has been considered by colonial administrators to suffer the effects of overpopulation (Allan 1965; Carswell 2002), particularly low soil fertility and soil erosion. Colonial governments supported the development of bench terraces, planting of trees, and in Rwanda and Burundi the promotion of small-holder coffee. The average farm size in Rwanda is 0.76 ha, with the higher population regions averaging around 0.6 ha (Ndayambaje 2013).

The ability to continue to absorb an increasing rural population was accomplished by conversion of wetlands, cultivation of more marginal land on hilltops and judicious fallowing (Figure 5.2). This resulted in plot fragmentation across different land use forms. Livestock, particularly cattle, are not as widespread in the system, except in Bukoba. As access to limited forest areas declined, trees for fuelwood were incorporated into the farming system (Ndayambaje 2013). Cropping patterns varied by agroecology, with the high-altitude areas being dominated by annual monocrops, particularly potatoes, peas and

Figure 5.2 Fragmented fields on densely cultivated hillsides on Lake Kivu shores in Gisenyi, Rwanda.

Source: Mory Haba.

brassicas. The more mid-altitude areas were dominated by intercropping of annuals along with coffee and EAHB, especially beans and root crops. The wetland areas were planted to rice, horticultural crops and taro. The system produces a relatively continuous supply of food through the two planting seasons.

Trends and drivers of intensification and diversification in the highland perennial farming system

The highland perennial farming system and its six subsystems represent a range of overall agricultural development patterns. Given the high agricultural potential, the relative lack of medium- or large-scale agriculture (apart from the occasional coffee or tea estate) and the pressure on farm size, the evolution of the farming system provides insight into the role of markets and sustainable smallholder development strategies within the six African countries involved.

Rural population drivers

East Africa, like the rest of Africa, has experienced high rates of urbanization. Nevertheless, compared to coastal West Africa or the mineral economies of southern Africa, East Africa is still at a relatively early stage of transitioning to an urbanized population structure. In 2010 among the five principal East African countries (excluding Tanzania and DRC),² Kenya had the highest percentage of its population in urban areas (22 per cent), and Burundi and Uganda the lowest (13 per cent). In virtually all countries the rural population is expected to increase until 2050. In 1960 the urban population in Rwanda, Burundi, Kenya, Uganda and Ethiopia together was only 2.5 million, compared to about 30 million in 2010. In the post-colonial period the size of urban markets grew to the point that they would become more important

than export markets in absorbing marketable surpluses from farms. At the same time arable land per head of agricultural population more than halved in the period 1960 to 2010, from 0.51 ha to 0.20 ha in Ethiopia and from 0.46 ha to 0.22 ha in Kenya. In 2010 Uganda had the highest arable land per head at 0.35 ha and Rwanda, Burundi and Ethiopia were all below 0.20 ha. This represents an average cultivated area of between 1–1.5 ha per household. In a national survey in Kenya the average arable area per person was 1.4 ha but only 0.8 ha in the central and western highlands (Kimenju and Tschirley 2008).

Market drivers and changing policies and institutions

The post-colonial period from independence until structural adjustment and market liberalization in the 1990s was very different across the six subsystems. The Albertine Rift region and Ethiopia were characterized by civil disorder for virtually all of the 1970s and 1980s, culminating with the Rwanda Genocide of 1994. Market development and private sector investment under such conditions was highly constrained and these two subsystems in large part reverted to a subsistence orientation, where food surpluses sustained urban markets. In Ethiopia the period was characterized by a continuous series of crop failures and famine situations of varying magnitude.

In the Albertine Rift the redefinition of market institutions in the 1990s consisted of ensuring public security and encouraging the private sector to invest in road infrastructure in order to rebuild the markets that had been destroyed during the civil disorder. In Uganda institutional development was facilitated by a programme of administrative decentralization. In Ethiopia institutional strengthening also consisted of developing a federal administrative structure, as well as significant investment in agricultural research and extension. Market liberalization, however, was slow and the agricultural sector still had a large public sector participation. In Kenya and Tanzania liberalization of foreign exchange and agricultural input and output markets were very much an incremental process, which created uncertainty for private sector investment. However, by the turn of the century this process had been consolidated and the stage was set for increased integration of East African subsystems into expanding agricultural markets.

East African subsystems can be separated into those which have already integrated into markets, namely central Kenya and Kilimanjaro, and those that still rely on semi-subsistence subsystems. The latter are only at the initial stages of responding to market opportunities, and the central question is how they will change with increasing integration into markets. It is expected that the degree of market participation will vary across the six subsystems based on differences in market drivers, transport infrastructure and relative competitiveness between sub-regions.

The principal urban markets in the East African highlands are relatively insulated from import competition, due to the distance from the ports. Even Nairobi is 500 km from its principal port. Rapid growth in urban population and rising incomes have diversified the number of food commodities that serve as cash crops. Higher value commodities such as horticulture and dairy have expanded rapidly in smallholder systems in Kenya and northern Tanzania, with transport and agroecology being important determinants of integration of these activities into the highland perennial farming system.

Smallholder dairy is expanding in the Albertine Rift region, with Rwanda's one-family-one-cow programme being a good example of this process (discussed later) with significant implications for the sustainability of the farming system. This trend towards increased value-adding in East African subsystems is also reflected in traditional export

crops. Virtually all the countries in the region, except DRC and Burundi, have moved to developing high value, specialty coffee value chains. Similarly, smallholder tea continues to expand in Kenya, which has become a global leader in tea exports and in export horticulture.

Investment in, and expansion of, input markets has lagged behind the expansion of commodity markets. Seed companies have led in this area during the 2010s, especially for hybrid maize, and this includes private sector investment in tissue culture bananas in Kenya, Uganda and Burundi. Development of fertilizer markets has particularly lagged well behind, except in Kenya, and is dependent on the development of networks of stockists of agricultural inputs. Nevertheless, fertilizer is a key input in the sustainability of East African subsystems and the East African highlands face the difficult trade-off between the very high cost of delivering such a bulky input commodity versus the high rates of nutrient depletion in systems, especially as they move to increased offtake and sales of farm production.

Another important market driver is the development of regional economic communities, especially COMESA and the revitalization of the East African Community, that promise increased interregional trade in agricultural commodities, including processed foods and feeds. At the same time such trade is being facilitated by investment in road infrastructure, particularly the paving of major north-south roads to complement the east-west corridors. As Kenya moves into a persistent net import position for maize, this opens markets for Ethiopia, Uganda and Tanzania. Uganda, in particular, sits at the middle of trade routes to southern Sudan, DRC and Kenya. Whether this will result in a regional comparative advantage and increased specialization remains to be seen.

The latest approach to linking markets, private sector investment and agricultural development in Africa is the Agricultural Growth Corridor (Kuhlmann et al. 2011). The strategy is to build private sector investment and agribusiness clusters around primary rail and road links to ports, supported by creative financing mechanisms funded by international development agencies. The Southern Agricultural Growth Corridor of Tanzania is one of two initial pilots and focuses on agricultural development linking the southern highlands to both export and domestic markets, particularly in Dar es Salaam. This initiative is in its initial stages and it is too early to see how private sector investment will respond. How this initial pilot might influence agricultural development planning for the Albertine Rift and southern Ethiopia subsystems – that are far from port areas and must cross international borders – remains to be seen.

Natural resources and agroecology

Temperature, more than rainfall, differentiates subsystems by altitude in the highlands, especially wheat, potatoes and peas compared with sorghum, maize, cassava and beans. Climate change, especially increasing temperatures, is already apparent in the climate records (Stern et al. 2011) – temperatures in highland areas have increased from 1.38 to 1.68 degrees over the 1966–2006 period. Rising temperatures will create more pressure to expand agriculture into the forest areas of the highlands. Many of these are already under threat. Temperature change is leading to the loss of optimal production zones for arabica coffee and lowering productivity in the East African highlands (Ridley 2010). However, it is the tightly linked interactions and feedback loops of land use change, soil fertility management, and pest and disease dynamics that are setting limits on the farmers' ability to increase productivity.

Land use change

The highland perennial farming system since the 1960s has been moving away from the use of common property resources to management of individual property rights, and the conversion of natural ecosystems, particularly forest, wetlands and grasslands, into cropland. The land use change first involved extensification and then intensification, and was moderated by changing tenure rules. In the highlands around Mt Kenya the shift in tenure occurred in the late 1950s with the adjudication of land, including communal grazing into private farms. Livestock numbers declined and farming moved to higher value cattle and zero grazing, incorporating forages into the cropping system. Tree planting increased, especially as boundary planting of exotic species. A similar process took place on Mt Kilimanjaro, particularly after the abolition of chiefs in 1962 (Misana 2012) and private farms were established (Figure 5.3). In areas such as Kabale in southwest Uganda, there was a progressive conversion of wetlands to cropland, beginning at the wetland margins and progressing to full conversion (Puhalla 2009).

Soil fertility and land degradation

Managing soil fertility under increasing population density and falling farm size is a central issue in understanding farming system dynamics (Allan 1965; Ruthenberg 1971), and the East African highlands provide numerous examples of pathways in the development

Figure 5.3 Large-scale coffee plantation on Mount Kilimanjaro, Arusha area, Tanzania. Note the presence of scattered shade trees throughout the plantation.

Source: Fabrice Pinard.

of permanent, rainfed systems and the evolution of nutrient management strategies. Perennial systems, such as highland banana, tended to be located on the more fertile soils, often augmented by manuring from stall-fed cattle. These subsistence-oriented systems maintained a significant yield equilibrium but were quite labour intensive in both crop management and fertilization. However, recent loss of labour, increased marketable surpluses and restrictions on feed resources are resulting in an inability to maintain that equilibrium, exacerbated by increased pest and disease attacks (see next section). This has also resulted in the development of declining nutrient gradients moving away from the household (Okumu et al. 2011).

Those highland subsystems that were more dependent on annual crops or were evolving in that direction, for example the higher altitude in the Albertine Rift or the subsystems in western Kenya or southern Tanzania, had more difficulty maintaining soil fertility as they moved to annual systems. Tillage in these systems increased erosion, introduced higher rates of decomposition of organic matter and led to low rates of nutrient cycling and higher rates of nutrient depletion. In these subsystems limited nutrient sources tend to be concentrated on the better plots resulting in highly variable fertility across plots and marked nutrient gradients (Tittonell et al. 2005). Retaining livestock within the system and associated manuring are critical to sustaining annual crop yields, although at a low level. Mineral fertilizers are currently seen as essential to maintaining crop productivity in these systems, but response to fertilizer application and therefore its profitability depends on how 'degraded' soil organic matter and nutrient status have become, with the result that some systems find themselves essentially in a poverty trap (Tittonell and Giller 2013).

Education and human capital

Investment in human capital in rural areas can be a significant driver of farming system change and improved productivity, but the effects depend very much on context and opportunities. Farmer education and literacy can improve access to agricultural and communication technologies, can deepen social capital and farmer networks and associations, and can result in out-migration, which can either negatively impact labour use on farms and/or result in increased investments through remittances.

Market liberalization in the late 1990s, and the significant investments across the region in education and health during the 2010s, have resulted in significant gains in agricultural and labour productivity. Especially during the 2010s, countries across the region have invested heavily in primary education, especially Ethiopia, and enrolment rates in primary education in 2010 are similar across the region (World Bank 2015), although disparities across countries still remain for secondary education. Allen et al. (2012) demonstrated particularly high returns to district level education investments in both the Kilimanjaro and southern highlands regions in Tanzania. Moreover, where farm size is particularly constrained, as in central Kenya, Shreffler and Nii-Amoo Doodoo (2009) found that investing in children's education "is adopted as a substitute for land inheritance when land resources are scarce". In the East African highlands both rural labour markets and migration will continue to adjust to increasing investments in rural education, especially where urban employment opportunities remain limited.

Science and technology

Agricultural research and technological change are key drivers of farm productivity and will be essential in supporting agricultural intensification and diversification in the East

African highlands. However, the fragmented spatial distribution of the highlands, and the long-term investments needed to undertake research on perennial crops and systems, has in many ways limited the development of research capacity for this agroecology. For countries such as Tanzania, Ethiopia and Uganda, the humid highland areas are restricted in size compared to agriculture in the country as a whole, and they have limited research infrastructure. Rwanda and Burundi face the classic small country problem, and it is primarily Kenya that has invested in research on the highland perennial farming system. But, even in Kenya, there tends to be a focus on cereals and grain legumes. The focus for these crops, and for roots and tubers, tends to be maintenance research, particularly managing the ever changing pest and disease complex. The only fully multidisciplinary research team working on EAHB is in Uganda. Coffee research is limited, especially as there are few international research programmes with which to link.

The research challenge for the East African highlands is in developing sustainable systems of soil, nutrient and land management (Tittonell and Giller 2013). Nutrient use efficiency is critical where the price of mineral fertilizers is so high, and this requires effective targeting of fertilizer blends – which are only just beginning to appear in the East African region – and mixing with high quality organic fertilizers with a focus on improving soil organic matter. As these subsystems commercialize and result in higher rates of nutrient extraction, profitable methods of soil and nutrient management become key to sustainable intensification, alongside exploiting the genetic potential of improved varieties. Integrated soil fertility management is a dominant approach to the problem. These research threads are only now being integrated under what is being termed sustainable agroecological (or system) intensification (Keating et al. 2013).

Energy

Because of the small farm size and the ready supply of casual labour, energy for farming activities relies essentially on human labour with often strong divisions based on gender. There is little use of oxen, limited to the less populous areas of southern Tanzania, or mechanical technologies. Nevertheless, there are still labour constraints at the period of planting and first weeding and for labour-intensive soil fertility maintenance practices. Under such conditions there are limited options to increase labour productivity and agricultural wages, with herbicides being one possible option.

Household energy is dependent on fuelwood. The lack of common property resources both puts pressure on the limited areas of forest reserves, with negative effects on downstream hydrology, and at the same time fosters integration of trees into the farming system. Trees are an essential resource in highland ecologies, but energy is not a driver of intensification of these subsystems.

System performance

The highland perennial farming system is at something of a juncture. As outlined earlier, the process of moving to permanent systems, where fallowing is not possible and grazing and fuelwood must be integrated into the farming system, is virtually complete. Yet rural populations continue to grow, farm size is declining and the potential for moving into more marginal agricultural areas is limited for all of the subsystems. Improved access to markets offers an array of options for improving total farming system productivity (including food and cash income), as well as diversifying livelihoods through participation in the broader rural non-farm economy (RNFE). This section assesses system performance by

examining intensification and diversification strategies of the highland perennial farming system during the 2010s since structural adjustment and market liberalization, particularly in relation to reducing poverty in the six subsystems.

Conceptual framework

The critical drivers of system change in the highland perennial farming system are rural population growth (and the associated decline in farm size) and improved market integration. Given that these are permanent systems, both drivers in turn influence the sustainability of the natural resource base, especially soil health. Given that increased offtake for markets requires nutrient replacement, participation in fertilizer markets is in turn a principal determinant of both productivity growth of the system and the generation of marketable surpluses. Because of the productive potential of the highland perennial agroecology, market participation allows potential diversification into higher value production activities as well as productivity growth in existing activities and thus overall system intensification. The potential for such market-led system intensification in turn depends on speed and level of investment in market infrastructure that supports smallholder access to market and in turn improved efficiency of smallholder-based input and output markets. The latter depends on relative proximity to and size of principal urban markets and the density and state of road transport infrastructure. Market efficiency is related to overall economic development; to government investment in roads, education and service delivery institutions; and to the vibrancy of the private sector in input retailing, product aggregation, grading and storage points, supply of truck and transport capacity. Market efficiency also determines potential off-farm income (employment and RNFE investment options) for farmers.

The pathway for system intensification thus interacts directly with the broader market context. This market context varies across the six subsystems and defines the potential for market-led intensification and thus the ability to intensify with shrinking farm size. An assessment of these three pathways for the six sub-regions is presented in Table 5.6.

To provide some perspective on the role economic conditions and private sector market investment play in influencing farming system structure and intensification pathways, FASID conducted farm surveys comparing Kenya, Uganda and Ethiopia in 2004

Table 5.6 Market-driven intensification pathways in highland perennial farming subsystems

<i>Farming system intensification pathways;</i>	<i>Commercializing: central Kenya and northern Tanzania</i>	<i>Diversifying: Albertine Rift, southern Tanzania and western Kenya</i>	<i>Stagnating: southern Ethiopia</i>
<i>Household strategies</i>			
Cash crop growth or diversification	Specialization Differentiation	Diversification	Static to declining
Staple crop intensification	Increasing yields	Livelihood dependent	Static to declining
Soil fertility management	Fertilizer	Integrated soil fertility management	Organic material
Off-farm income growth	Significant	Emergent	Limited
Exit from agriculture	Push and pull	Limited pull	Push

Note: For definitions of terms, see chapter text.

Table 5.7 Farm income based on surveys in Kenya, Uganda, and Ethiopia, 2004–2006

<i>Kenya</i>	
Per capita income (US\$)	367.0
% crop income	35.8
% livestock income	24.2
% non-farm income	41.5
<i>Uganda</i>	
Per capita income (US\$)	153.9
% crop income	64.0
% livestock income	12.7
% non-farm income	29.2
<i>Ethiopia</i>	
Per capita income (US\$)	93.7
% crop income	52.5
% livestock income	34.0
% non-farm income	11.6

Source: Yamano and Kijima (2010).

and 2006. Farm income comparisons (Table 5.7) demonstrate the more advanced market development in Kenya, where per capita farm income was more than double that in Uganda, and three times that of Ethiopia. In the Albertine Rift in Uganda there is much more dependence on crop income compared to both Kenya and Ethiopia. In the latter, the plough, draught power and livestock have traditionally formed an important part of the subsystem, particularly compared to the Albertine Rift. Moreover, the potential for off-farm income is significantly higher in Kenya than the other two countries. Especially in Ethiopia, this is the principal reason for classifying the development pathway as stagnating (Table 5.6).

The highland perennial farming system in general includes production of a subsistence component, but the proportion between subsistence and market sales varies depending on market efficiency. Farmers react to market incentives based on relative prices (farmer terms of trade) in deciding on providing for subsistence needs versus either expanding marketable surpluses of staple food crops or shifting into purely cash crops. For farmers not well integrated into markets the price of selling the staple is low compared to the high cost of buying the staple during the “hunger” season. With such small farm sizes a farmer’s shift into cash crops will depend on the ability to intensify the production of the staple food crops, thereby releasing land for cash crops, and purchasing the staple food crop at a reasonable price when supplies are short, namely relying on efficient and well-integrated staple food markets.

The three intensification pathways reflect this progressive integration into markets. The commercializing sub-regions have been integrated into markets and have diversified into cash crops, with the question being whether they have reached a tipping point where the system moves to increased specialization in the most profitable, usually higher value crop. Because of the slower rate of development of staple food markets compared to cash crops (Kimenju and Tschirley 2008), most farms will tend to diversify further, at least

initially, in response to market opportunities for cash crops. With continuing improvements in market integration for staple food crops, farms will eventually move towards greater specialization. The diversifying sub-regions have lagged in terms of private sector investment in market infrastructure, but prospects are favourable for increasing such investment, and thus a pathway of increasing diversification into higher value crops or livestock. The stagnation pathway is one where intensification options are limited and average farm size has declined to levels that do not support productive livelihoods.

Finally, to evaluate the impacts of system intensification on poverty, the variation in household livelihoods within the sub-region needs to be understood. Such socio-economic differentiation is essentially due to variation in household assets, especially land but moderated by education level. Several studies have developed typologies of household livelihoods, and a typical classification of livelihoods in the highlands from lowest to highest income potential is as follows: (1) subsistence plus unskilled wage labour, (2) mixed smallholder (some wage labour), (3) staple producers (no wage labour), (4) off-farm skilled employment and (5) diversified commercial (Brown et al. 2006). Three of these livelihood strategies involve non-farm activities, which suggests that most households cannot meet needs just from the farm. Salaried employment and commercial production offer the most household income potential but depend on household assets and the quality of human and natural resource capital. The lower income strategies involve trade-offs in terms of availability of labour for on-farm work vs casual employment and income for investment in farm enterprises versus household consumption. Market participation will depend on the asset base of the household and through labour and land markets can result in shifts in land distribution and access to land, with implications on poverty rates. Understanding impacts on poverty as the systems intensify thus requires tracking differentiation of households in terms of their livelihood strategies.

The following analysis further examines the subsystem categorization as well as the farming system and livelihood dynamics.

Development pathways in the commercializing subsystems (central Kenya and northern Tanzania)

Research done through the Tegemeo Agricultural Policy Research and Analysis (TAPRA) projects supports this hypothesis that the central Kenyan highlands are commercializing.³ The area has a higher level of diversification than other agroecologies in Kenya, plants less maize as a proportion of total area, and plants a higher percentage of cash crops, including for dairy.

In 2007, on an average cultivated area of 0.80 ha (similar to that in the western highlands), central Kenyan subsystems derived 71 per cent of their income from crop and livestock activities (the highest for any sub-region), and allocated only 35 per cent of the arable area to maize (compared to an average across Kenyan smallholders of 54 per cent), with an increased area of commercial cash crops, and fodder crops used to feed improved breeds of cattle (Table 5.8). The average number of 14 crops in 2007 was the highest for any of the highland perennial subsystems.

For the future the question is the limits on diversification into cash crops. Brown et al. (2006) developed five livelihood clusters in the Kenyan highlands and demonstrated that the superior cluster is what they call 'diversified commercial'. In this strategy, represented by 5 per cent of sampled farmers in Embu (central Kenya) and none in Vihiga (western), households put far less emphasis on food crop production. They devote as much land

Table 5.8 Comparison of diversification in the central and western highlands of Kenya

	<i>Central highlands</i>	<i>Western highlands</i>
Number of crops	14	13
% land in maize	35	42
% land in commercial cash crop	35	19
% land in fodder crops	22	11

Source: Data supplied by Tegemeo Institute under the Tegemeo Agricultural Policy Research and Analysis II Program (Tapra II Program).

area to perennial fodder production as they do to annual food crop production – and put nearly 70 per cent of their land into perennial cash crops, mainly tea and coffee. Their farming operations integrate relatively large improved dairy herds and sizable small ruminant herds to constitute highly diversified commercial farms. They have no local dairy cattle and no household members engaged in unskilled employment, but do supplement their on-farm income with some skilled, off-farm employment. This livelihood strategy is the only one that generates an average per capita income greater than a dollar a day. Farm sizes in this cluster averaged around 3 ha (compared to Allan's notion of 2.4 ha as a viable farm size in the Kikuyu highlands).

In the central Highlands farm size is critical to providing an income level above the international poverty line, as well as allowing farmers to integrate into new or emerging market opportunities. Two studies characterizing farmers in the central highlands show that farms supplying horticultural produce to supermarkets (rather than traditional wholesale markets) tend to be larger, better educated, primarily specialize in horticulture production, hire more labour per hectare and are better capitalized with irrigation and other infrastructure (Neven et al. 2009; Rao and Qaim 2010).⁴ The Neven study found that mid-sized farms averaging between 9 and 18 ha characterized the diversified commercial livelihood class. This compared to suppliers to the spot cash market that averaged between 1.5 to 2.5 ha, which is still a large farm size for the central highlands. Equivalent farm sizes for the Rao and Qaim study were 1.1 ha and 0.76 ha and net income per hectare for the supermarket suppliers was more than double that for the wholesale market.

These findings suggest that the better resourced, larger farms will be the ones that take advantage of the most profitable market opportunities, and that they will tend to specialize, representing a shift from diversification. At the same time, the majority of farmers without the asset base will have to seek other livelihood strategies. As Losch et al. (2012: 167) found:

[a]n initial increase in the participation of smallholders in modern value chains, was frequently followed by their progressive marginalization as larger producers enter the market and are able to provide more supply with the required quality. This progressive differentiation among producers is exacerbated by the practices of major retailers and by supermarket procurement systems. As supermarkets and major retailers try to facilitate the adoption of their specifications and reduce their transaction costs, they often choose to work with a reduced number of suppliers that can provide high volumes and high quality.

The expected trend is that these commercial farmers will tend to buy land and increase their scale of operation. In higher wage labour markets such as the central highlands,

the poorer households will tend to move more into supplying permanent, wage labour. The larger growth, however, will be in households that maintain small home gardens but participate in the growing RNFE. Growth in the RNFE depends on growth in the local farm sector (Haggblade et al. 2010), and that in turn on expansion in the numbers of small-scale commercial farmers, but with a minimum farm size probably around 1 ha. These farms will diversify livelihoods, but will tend to specialize in farm production. Livelihoods across the farm size spectrum will continue to differentiate primarily in response to changing factor markets for land, labour and capital.

The Kilimanjaro region (northern Tanzania) is similarly poised in terms of a spatially restricted but highly productive agroecology, and highly improved road access to both Nairobi and Dar es Salaam markets. Effective market access has been relatively recent with the development of the Tanzanian road system in the early 2000s. Cash crop diversification has not been as extensive as in Central Kenya, but horticulture particularly has expanded, building in part on traditional irrigation systems and with some companies monitoring spraying and setting up traceability capacity in order to export to Europe. Labour and input markets are not as well developed as in central Kenya, and diversification into cash crops will continue without the farm size differentiation that is occurring in Kenya. At the same time the systems will increase reliance on mineral fertilizers, as Kilimanjaro together with the southern highlands have the highest usage rates across regions in Tanzania. Interestingly, maize is increasing in the Kilimanjaro region as part of the diversification into more annual crops, and more fertilizer is used on maize than on vegetables (Benson et al. 2012).

Development pathways in the diversifying subsystems (Albertine Rift, southern Tanzania and western Kenya)

The diversifying subsystems of western Kenya, the Albertine Rift and southern Tanzania are not as well linked to markets as the commercializing subsystems. They face higher transaction costs and marketing margins in participating in the markets and higher costs for fertilizer inputs, which limits their options. They are 'late arrivals' to diversification strategies and exhibit much smaller farm sizes (except southern Tanzania) than the commercializing subsystems. Broadly, there has been minimal structural change since the late 2000s or so for these subsystems, and a principal focus on intensification on food staple production. Marketing food staples has been the principal source of income.

The focus on staple food crop production, but with increasing marketable surpluses due to intensification, is reinforced by the relative isolation of these three agroecologies from international markets due to high transport costs. In a comparison of price transmission from international markets in Uganda for robusta coffee and sorghum, Kaspersen and Foyen (2010) found that food markets are not well integrated into world markets, while internal coffee prices were linked during periods of high world prices.

In the Albertine Rift, marketing surpluses of traditional staples that are bulky to transport is resulting in some geographical stratification. Ouma and Jagwe (2010) found that for banana markets in Rwanda and Burundi transaction cost-related factors such as geographical location of households, market information sources and travel time to the nearest urban centre influenced market participation. In the Albertine Rift region the relative importance of cooking bananas versus beer bananas appears to be related to market access, with cooking banana regions closer to markets than beer banana regions, where marketing is based on a higher value product. This is also broadly reflected in the dominance

of cooking bananas in Uganda with the large Kampala market versus beer bananas in Burundi with much more limited marketing opportunities.

As systems move towards a more commercial orientation, nutrients need to be replaced to ensure sustainability. Given the large nutrient offtake in commercial banana systems, there is an ongoing issue of how these systems can be made sustainable. Wairegi and Asten (2010) evaluated the potential role of fertilizer in Uganda and found that it is profitable only within a 160 km radius of Kampala, whereas the principal banana producing region in southwestern Uganda is much farther away. Fertilizer prices would have to be reduced by 50 per cent to be profitable in that region.

In these diversifying subsystems relative marketing costs have resulted in a shift towards annual cereal crops, which are far less bulky than the traditional bananas and root crops. However, this is more complicated than may first be apparent, again due to transport costs and the location of principal markets. Investment in marketing infrastructure in the Albertine Rift and in southern Tanzania has lagged significantly behind that in Kenya. This is reflected in much higher marketing margins for maize in Uganda compared to Kenya (Table 5.9). Marketing margins declined in Kenya and in the 2005–2007 period were 11 per cent of the market price, while in Uganda they were 37 per cent of the whole-sale price. Moreover, Uganda, because of limited domestic use, is a principal exporter of maize to Kenya, and the result is that farm-level prices in Uganda are on average 60 per cent lower than farm-level prices in Kenya.

Finally, since chemical fertilizer is imported into the region, fertilizer prices are much higher in the Albertine Rift than in Kenya, making the relative prices of inputs to outputs highly unfavourable in the interior countries. Thus, Matsumoto and Yamano (2009) found that fertilizer application in eastern Uganda is not profitable, whereas farmers in western Kenya are applying fertilizer at near the economic optimum. Intensification without reliance on chemical fertilizer is more management intensive, and in the Albertine Rift relies on the integration of grain legumes, fertilizer trees and high value dairy animals into the subsystem (Figure 5.4).

During the post-liberalization period from 1997 to 2004 there was a very strong diversification of Kenyan subsystems. Those in the western highlands became the most diverse

Table 5.9 Farm–market price spreads for maize in Kenya and Uganda

<i>Nearest market</i>	<i>2003/2004</i>			<i>2005/2007</i>		
	<i>Market price</i> (1)	<i>Farm-gate price</i> (2)	<i>Price spread</i> <i>% of (1)</i> (3)	<i>Market price</i> (4)	<i>Farm-gate price</i> (5)	<i>Price spread</i> <i>% of (1)</i> (6)
Kenya						
Nairobi	215.4	162.6	24.7	203.7	168.2	17.4
Eldoret	211.0	145.6	31.0	161.4	153.4	4.9
Kisumu	227.5	174.2	22.5	211.2	194.5	7.3
All	217.9	160.6	26.1	195.3	171.9	11.4
Uganda						
Kisumu, Kenya	188.1	106.4	43.4	187.2	98.4	47.4
Kampala	135.2	104.5	22.7	158.1	104.1	34.2
All	148.0	105.4	27.2	164.5	104.0	37.0

Source: Yamano and Arai (2010).

Figure 5.4 Industrial robusta coffee plantation intercropped with fast-growing leguminous trees in Mubende, Uganda, one of the few such industrial Robusta plantations in Africa.

Source: Fabrice Pinard.

and are continuing to diversify but at a slower rate (Figure 5.5). The proportion of arable land allocated to maize declined from 59 per cent in 1997 to 42 per cent in 2007. At the same time land allocated to fodder increased from 4 to 11 per cent and the proportion of improved breeds in the herd increased from 29 to 67 per cent, still less than the central highlands (95 per cent). The one-family-one-cow programme in Rwanda is attempting to do the same thing in the Albertine Rift, but with much less milk-processing infrastructure in place. While average farm size severely limits the herd size to below optimum, livestock significantly improves nutrient cycling in the farm and the overall sustainability of the crop yield component (Klapwijk et al. 2014).

Southern Tanzania has in many ways more potential for dairy but lacks the processing infrastructure and has high transport costs. The main trajectories for intensification in this system are yield improvement and increased commercialization of the principal staple together with greater integration of livestock, which partly compensates for nutrient out-flows with increased off-take of marketable surpluses.

Limits on intensification or diversification in a stagnating subsystem (southern Ethiopia)

The enset-coffee subsystem of southwest Ethiopia has persisted sustainably for centuries, but is moving towards unsustainability. Southwest Ethiopia has the highest average

Figure 5.5 Herfindahl indices of farming system diversification by agroecological zone in Kenya.
Source: Kimenju and Tschirley (2008).

population density of all the highland subsystems. In southwest Ethiopia the 2.2 per cent rate of population increase is causing farm sizes to fall below a critical size threshold, and RNFE might not be able to provide sufficient income. Average farm size in the onset ecology is about 0.5 ha (see Table 5.5 for the SNNP region), with over 60 per cent of households having less than that figure.

Such a subsystem provides a clear example of resource-based poverty traps (Barrett 2008) where farmers are unable to maintain system productivity due to system dynamics. Declining farm size and increasing but differential access to markets are leading to critical changes in these home garden systems (Abede et al. 2006). As farm size declines there is a shift away from the coffee cash crop to the onset food crop, a shift from indigenous trees on farm to *Eucalyptus*, and a reduction in livestock numbers. The loss of livestock is particularly critical, since livestock transfer nutrients from meadows to onset plots to maintain a positive nutrient balance (Hailelassie et al. 2006).

Poorer households tend to diversify into low remuneration activities – primarily trading – at the expense of labour for farm activities. On the other hand, commercialization has tended to increase the area under annual crops, particularly maize (which is less labour

intensive than onset), which has exacerbated nutrient depletion and loss of permanent cover. The functional components that underpinned subsystem sustainability are progressively being displaced for more immediate returns, with an overall loss in longer-term productivity.

Even given the favourable climatic and agroecological conditions, in 2000 the SNNP region (which primarily contains the highland perennial farming system) ranked last in measures of food security in Ethiopia. It had a hunger index of 50 (as defined by the International Food Policy Research Institute (IFPRI) (Schmidt and Dorosh 2009), which suggests a highly food insecure region. However, by 2005 the index had improved, approaching 30. The improvement might have been a result of the Productive Safety Nets Programme (PSNP), which had a positive impact on increased household calorie intake. As described by Gilligan et al. (2008), the objective of the PSNP is “to provide transfers to the food insecure population in chronically food insecure woredas (districts) in a way that prevents asset depletion at the household level and creates assets at the community level”. Safety nets are in many ways a policy of last resort, but their importance in this region reflects the limited options for alleviating poverty in an agroecology such as the southern Ethiopian highlands.

Strategic priorities

Agricultural change in the highland perennial farming system has a distinctive path dependency based on history, demographics and spatial determinants, particularly access to both export and growing urban markets. At issue is whether system intensification and diversification can compensate for a declining asset base in terms of farm size and, in many cases, declining soil capital and condition of ecosystem services.

Pathways to improve income and food security must either come from increasing net income from marketable surpluses (in some cases associated with buying-in staple food requirements), or from increased off-farm income, including non-farm employment and self-employment. In the latter scenario, there is a significant difference in potential incomes and welfare between participating in the RNFE as casual labour compared with permanent salaries, businesses or urban remittances. Losch et al. (2012: 151) note that “off-farm incomes have a very low value and constitute only a partial response to poverty, even if they can contribute significantly to overall household income in regions facing difficult agricultural situations”. Both migration and employment in the RNFE are part of a diversified livelihood strategy for the whole household, as well as continuing to manage and invest in their farms.

This section explores the potential for strategic interventions that can steer the three development paths towards sustainable intensification and rural poverty reduction. These two objectives will require quite different strategies given the distribution of land assets and livelihood options. The interventions discussed will focus on changing the incentive systems for farmers and on positively influencing the drivers discussed earlier.

Both government and private sector investors will need to consider existing economic opportunities and the principal constraints on intensification of these systems. These will vary across the three intensification pathways (Table 5.6). This argues for subsystem fine-tuning of government policies in order to meet the very different local needs and trajectories, both within the highland perennial system and across other farming systems in a particular country.

Development pathways for commercializing subsystems

Given the trend for larger farms, cash crop specialization and a growing RNFE, the strategies for technical, policy and institutional interventions for this subsystem revolve around balancing rural poverty objectives with increasing marketable surpluses of high value crops, particularly for growing domestic urban markets. A key consideration is how much effort should be focused on reducing transaction costs in land markets and facilitating land consolidation, as happened with the Kenyan development plan in the 1950s. This would speed up the move to larger farm sizes but create greater inequity in land distribution and reduce livelihood options for poorer households. Friction in the land market has been a principal constraint on movement towards larger farm sizes. Other sources of 'friction' include the lack of suitable off-farm employment, the tradition of dividing farms among all children, and the tendency for Kenyans to want to hold on to a rural homestead.

A minimum threshold farm size to maintain food security, and the integrity of the land resource base in the Kenyan highlands, has been estimated to be between 0.4 ha (Waithaka et al. 2006) and 0.7 ha (Stephens et al. 2012). These studies suggest that given efficient markets, this farm size threshold allows a sufficient asset base to diversify into dairy, maintain and invest in soil fertility, and develop cash reserves for reinvestment. The farm size group at this threshold and above will continue to intensify, and smallholder irrigation and improved timing of marketing, for example in the horticulture trade, will be increasing sources of increased productivity. Thus, Kenya is expanding investment in smallholder irrigation. However, these water resources are limited, have a dramatic influence on dry season stream flow at lower elevations, and are affected by climate change and the declining regulatory role of glaciers on both Mt Kenya and Kilimanjaro (Liniger et al. 2005). The mountains form two of the principal 'water towers' in East Africa, thus expanding irrigation must be balanced with other increasing demands on these limited water supplies.

Expanding farm size at one end of the land distribution implies declining access to land for those already below the poverty line. If on-farm and RNFE employment does not increase at a rate that can maintain livelihoods of the lower part of the income distribution, then exit from agriculture, i.e. permanent migration of the whole family, will be the principal option. This can be mitigated by safety nets, and these are often implemented through employment programmes. Success in gainful employment is in turn influenced by education level.

A result of declining farm size is that households have reduced their family size and invested more in the education of their children, in part because the intergenerational transfer of land has become non-viable (Shreffler and Nii-Amoo Dodoo 2009). Education, credit programmes to support small and medium enterprise development, and expansion into crop activities that generate employment further up the value chain, such as packing sheds for export horticulture, are all investments that will allow poorer households to tap into off-farm income opportunities.

A necessary complementary process to specialization in higher value crops is the development of efficient staple food markets. The commercializing highlands will move even further into being net importers of maize. This will have to be delivered through efficient staple food markets with reduced seasonal price volatility, controlled by improved grain storage and product flows. This may involve the delivery of higher quality, milled maize flour or improvements in local maize milling in the highland areas. However, home gardens will continue to provide the principal sources of nutrient dense products particularly

important for childhood nutrition. Biofortified crops such as orange-fleshed sweet potato and iron-rich beans offer the prospect of improved childhood nutrition.

Development pathways for diversifying subsystems

There are limits to diversification of farming in this subsystem given such small farm sizes. Changing farmer resource allocation into higher value cash crops in the diversifying highlands will be more difficult than in the commercializing highlands because the farm size constraint is more binding, putting priority on the staple food crops. Thus, in Rwanda coffee and tea account for only 2.4 per cent and 1.6 per cent respectively of the total value of agricultural production in the country (Diao et al. 2010). Farm size also limits the integration of a dairy animal into the system without access to external sources of feed, such as feed concentrates. The limits to farming will have to be compensated through diversification in livelihoods. The options open to poorer households in terms of RNFE will be fewer than in the commercializing sub-regions, but they will still be important in ensuring food security for these families.

Improving soil fertility management is a precondition for improving staple food productivity. A particular issue for the Albertine Rift, where vegetatively propagated crops dominate as food staples, is a possible shift to grains as a means of integrating national staple food markets and, if so, the impacts of annual cropping on the sustainability of the land resource base. For example, Rwanda's strategic plan for crop intensification focuses primarily on cereal crops, and EAHB is not a priority crop. There is a particular focus on maize, rice and wheat, although cassava, potatoes and beans are also priorities (Kathiresan 2011). However, in terms of national agricultural production, root crops and EAHB currently make up 51 per cent of national agricultural production while cereal crops account for only 8.8 per cent (Diao et al. 2010). This suggests a dramatic shift calling for expensive fertilizer imports. There has also been little investment in research on the starchy staples in the highlands, particularly EAHB, cassava, sweet potatoes and Irish potatoes, especially in terms of appropriate nutrient management strategies for these crops.

Government policy in each of the countries is focusing on market development and commercialization of smallholder systems. Fertilizer markets are a critical component of these policies. Except for Kenya, the highland perennial system countries still face the challenges of the small size of domestic markets for fertilizer, inability to achieve scale economies in imports and distribution, very high transport costs, high fertilizer prices, and therefore limited farm-level profitability. Fertilizer subsidies have been a policy mechanism in Rwanda, Tanzania and Kenya, and have evolved to smart subsidies through targeted voucher programmes. These rely on the development of agrodealer networks which should allow movement away from government procurement to reliance on private sector import and wholesaling operations.

Nutrient use efficiency (NUE) will be an essential element of intensification in the diversifying highlands. This will be achieved by combining inorganic fertilizer with organics, improved management of manure, optimizing biological nitrogen fixation with fertilizer trees and grain legumes (often in terms of phosphorous application), and fertilizer blends that adjust to the requirements of different crops, especially cereals versus grain legumes versus root and tuber crops. Achieving improved NUE, and therefore return on purchased nutrients, will involve significant improvement in farmer management of crop nutrition, potentially combined with concentration of nutrients in planting holes and

movement towards reduced tillage and conservation agriculture with trees. Cash crops will probably lead to farmer adoption of fertilizer, which will generate the cash that will allow increased use of fertilizer in the staple food crops.

Most countries in the region have moved towards increasing value-adding and quality of coffee production. Thus, Rwanda has moved from producing only 2 per cent fully washed coffee in 2002 to 12 per cent in 2006 and to 20 per cent in 2010 (Figure 5.6). However, this is well below the target of 85 per cent in 2012 and has not kept pace with the investment in processing factories and washing stations – 1 in 2002, 74 in 2006 and 188 in 2010 (World Bank 2011). The principal tendency in the diversifying highlands has been to move towards horticultural production, including higher value root crops such as potatoes, and grain legumes. The intent is to serve domestic and potentially regional markets, but the area that can meet such market demand will still be limited and dependent on good access to road infrastructure.

Potentially, the largest impact on pathways for diversifying subsystems will be their closer integration into the larger regional markets through the East African Community and COMESA for the southern Tanzania highlands. This should reduce transaction costs at borders in the delivery of inputs such as fertilizer, potentially open up regional feed markets, provide better price integration across urban markets and lead to better exploitation of the agroecological comparative advantage of the highlands. It is expected that agribusiness investments will also follow, resulting in a much more dynamic RNFE.

Figure 5.6 Coffee washing at COOPAC's Nyamwenda washing station in Gisenyi, Rwanda.
Source: Jean-Marc Boffa.

Development pathways for stagnating subsystems

The southern Ethiopia highlands appear to have reached something of a Malthusian limit where government intervention is primarily framed in terms of safety net programmes. This is a necessary short-term strategy, but it can be complemented by more medium-term and long-term strategies including education and slowing down rural population growth through family planning policies (Headey et al. 2013). These longer-term strategies should be pursued despite shorter-term constraints posed by the unusually small size of the rural non-farm economy (although small towns in Ethiopia are growing rapidly).

More medium-term interventions need to focus on the farming subsystem itself. Increasing the productivity of *enset* would be one means of maintaining the integrity of the *enset*-coffee subsystem. But there has been virtually no research on *enset*, and achieving any gains in the short term is probably limited. Bacterial blight and maintaining soil fertility are two principal constraints.

This subsystem has the lowest use of fertilizer in Ethiopia, thus developing fertilizer markets, particularly blends suited to the nutrient requirements of *enset*, would be valuable. Increased fertilizer use would require increases in cash availability, which argues for improving the productivity of coffee in the home garden systems. Coffee yields in these systems are in the range of 600 kg/ha, compared to double that on large farms (Taffesse et al. 2011). Probably as important will be the impacts of rising temperatures due to climate change on arabica coffee productivity, both the effect on crop physiology and the expansion of pests and diseases. Coffee berry borer is already expanding and having significant negative impacts on crop yields (Jaramillo et al. 2011). Just maintaining productivity of these systems is going to be a major challenge in the medium term, much less achieving significant improvement.

Exploiting the agricultural potential of this region will rely on longer-term investments in road infrastructure, education and family planning. Ethiopia has made great strides in investing in its agricultural sector during the 2010s. However, there has been a principal focus on improving productivity in the cereal-based systems that are better integrated with principal urban markets. Evidence suggests that there has been major structural transformation and improved efficiency in cereal markets in the country since the late 2000s (Minten et al. 2012). In large part this has been due to significant investments in road infrastructure and travel times have indeed decreased (Schmidt and Kedir 2009). This has been reinforced by policies in support of fertilizer, hybrid seed and extension that particularly favour cereal-based systems.

However, these investments have not extended into the southwest region, which remains largely unintegrated into the national agricultural market system. The *enset*-coffee subsystem of southwestern Ethiopia thus faces the dual challenge of loss of structural sustainability from declining farm size and inability to take advantage of market-driven intensification due to lack of integration with the broader growth dynamics within the Ethiopian agricultural sector. The *enset*-coffee subsystem will require its own specific development strategy and greater equity in sub-regional investment by the federal government (Figure 5.7).

The potential for poverty reduction

In summary, the poor in the East African highlands are asset constrained in terms of land, human capital and financial capital. There is virtually no scope for improving access to land for poor households, either due to larger farms buying smaller farms in the commercializing

Figure 5.7 Agricultural landscapes around Jimma, Oromya region, Ethiopia.

Source: Fabrice Pinard.

subsystems or to continued population growth in the other two subsystems. Moreover, access to financial capital through credit markets requires such land assets. The pathways to escape poverty are limited in the highlands (Tables 5.10 and 5.11) and essentially rely on off-farm employment, either urban or in the RNFE. The diversifying subsystems have somewhat larger average farm sizes and some potential for diversifying into cash crops, which offers a little more scope for increasing incomes from farming, but for the poor this will still be limited. The highland subsystems have been a persistent source of outmigration and will continue to be so into the medium-term future. However, urban employment remains limited and is primarily informal. Poor households will need to continue to pursue highly diversified livelihood strategies in both rural and urban sectors.

Table 5.10 Relative importance of household livelihood improvement in the highland perennial subsystems

<i>Livelihood improvement strategy</i>	<i>2015 Commercializing</i>	<i>2015 Diversifying</i>	<i>2015 Stagnating</i>	<i>2015 Overall</i>
Intensification	1	1	1	1
Diversification	1	2	2	2
Increased farm size	0	0	0	0
Increased off-farm income	4	3	1	3
Exit from agriculture	4	4	6	4

Source: Estimates by chapter author.

Table 5.11 Relative importance of household livelihood improvement strategies*

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total ag pop	—	51	49	100
Intensification	1	1	2.5	1.5
Diversification	2	2	3.5	2.5
Increased farm size	1	0	1	0.5
Off-farm employment	2	3	2.5	3
Exit from agriculture	4	4	0.5	2.5

Sources: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

*See Chapter 1 for definitions of the five household strategies.

System conclusions

For the highland perennial farming system in East Africa, the 2010s has been a time of consolidation after periods of insecurity in many countries, and redirection after liberalization of agricultural markets. A decade is not long enough to interpret the future evolution of the system, but the experience to date suggests a diversity of responses across the six highland perennial subsystems and emerging constraints and options for sustainable intensification of these subsystems. While improved access to markets has been the principal driver of change, the continued primacy of subsistence objectives and the maintenance of the farming system's basic structure around the principal food staples are also striking.

At the same time, other drivers continue to exert influence on farming system development pathways, particularly continued rapid rural population growth, periodic biotic challenges, especially in the Albertine Rift, and William Allan's principal driver, the maintenance of soil fertility. Declining farm sizes, persistent risk factors such as plant diseases and limited options for improving soil fertility will continue to be principal constraints or influences on intensification pathways for increasing commercialization and integration into markets.

The inherent path dependency in farming system structure and evolution, and the inertia in farming system diversification due to meeting household subsistence objectives, contrasts sharply with the policy objectives of governments in the region. The highlands in general are home to a significant percentage of these countries' rural population, and they produce the bulk of their cash crops. In general, they are relatively well served by road and transport infrastructure and are expected to produce increasing marketable surpluses of its food staples.

The highlands are key to economic growth, food security and rural poverty objectives of these governments, and yet questions remain about the future growth potential of the highland perennial farming system, compared with the less densely settled farming systems with lower agricultural potential. Possibly the most significant question in the highland farming system is the minimum farm size required to be economically viable and to generate marketable surpluses (Hazell 2011). Growth will need to come from intensification and improved efficiency of existing cropping enterprises, shifting the production frontier through improved technical change and productivity, and diversifying to higher value crops.

Larger farms – in the East African highlands these are usually anything over 1.8 ha – have an inherent advantage in achieving these conditions. The largest percentage and density of rural poor are also in the highland areas. Thus, raising the productivity of these

farms, even if they remain net buyers of food staples, will contribute to reducing rural poverty and malnutrition. The question is whether commercialization will be an avenue to reducing poverty or will further marginalize those with limited resources other than their labour.

Notes

- 1 Subsystems in this chapter are essentially sub-regions distinguished by different market contexts.
- 2 Tanzania is not included in FAOSTAT (2010) and national statistics for DRC do not adequately reflect the context for the eastern highland region of DRC.
- 3 This discussion of the Kenyan highlands draws on various research reports of the Tegemeo Institute. These research reports analyse a nationally sampled panel survey of 1,275 households carried out in 1997, 2000, 2004, 2007 and 2011. This is the most comprehensive data set to analyse changes in farming systems in the post-liberalization period in Kenya.
- 4 The farm sample for the Neven study was drawn from a list of suppliers for the two largest supermarkets in Nairobi, while the sample for the Rao study was drawn from farmers in Kiambu district, oversampling for supermarket suppliers.

References

- Abede, T., K.F. Wiersum, F. Bongers and F. Sterck. 2006. Diversity and dynamics in home gardens of southern Ethiopia. In B.M. Kumar and P.K.R. Nair (eds) *Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry*. Springer, pp. 123–142.
- Abede, T., K.F. Wiersum and F. Bongers. 2010. Spatial and temporal variation in crop diversity in agroforestry homegardens of southern Ethiopia. *Agroforestry Systems* 78: 309–322.
- Allan, W. 1965. *The African Husbandman*. Oliver.
- Allen, S. L., O. Badiane and J.M. Ulimwengu. 2012. *Government Expenditures, Social Outcomes, and Marginal Productivity of Agricultural Inputs: A Case Study for Tanzania*. IFPRI Discussion Paper 01172. IFPRI.
- Anderson, L. and M.K. Gugerty. 2012. *Tanzania National Panel Survey. Living Standards Measurement Study: Integrated Surveys on Agriculture – Inputs*. EPAR Brief No. 179, Evans School of Public Affairs.
- Baijukya, F.P., N. de Ridder, K.F. Masuki and K.E. Giller. 2005. Dynamics of banana-based farming systems in Bukoba district, Tanzania: Changes in land use, cropping and cattle keeping. *Agriculture, Ecosystems & Environment* 106(4): 395–406.
- Barrett, C. 2008. Poverty traps and resource dynamics in smallholder agrarian systems. In R.B. Dellink and A. Ruijs (eds) *Economics of Poverty, Environment and Natural-Resource Use*. Springer, pp. 17–40.
- Bebe, B.O. 2003. Herd dynamics of smallholder dairy in the Kenyan highlands. PhD Thesis. Wageningen University.
- Benson, T., S. Kirama and O. Selejio. 2012. *The Supply of Inorganic Fertilizers to Smallholder Farmers in Tanzania: Evidence for Fertilizer Policy Development*. IFPRI Discussion Paper 01230. IFPRI.
- Brown, D.R., E.C. Stephens, J.O. Ouma, F.M. Murithi and C.B. Barrett. 2006. Livelihood strategies in the rural Kenyan highlands. *The African Journal of Agricultural and Resource Economics* 1(1): 21–35.
- Carswell, G. 2002. Farmers and following: Agricultural change in Kigezi District, Uganda. *The Geographical Journal* 168(2): 130–140.
- Central Bureau of Statistics (CBS). Ministry of Planning and National Development. 2003. *Geographic Dimensions of Well Being in Kenya: Where are the Poor? From Districts to Locations. Vol 1*. CBS.
- Central Statistical Agency (CSA). 2012. Agricultural Sample Survey 2011/2012, Volume IV, Report on Land Utilization. Addis Ababa: Central Statistical Agency.

- Diao, X., S. Fan, S. Kanyarukiga and B. Yu. 2010. *Agricultural Growth and Investment Options for Poverty Reduction in Rwanda*. IFPRI.
- FAOSTAT. 2010. FAO database, FAO Rome. www.fao.org/faostat/en/#data.
- FEWS-NET. 2006. *Southern Nation, Nationalities and People's Region, Ethiopia: Livelihood Profiles*. FEWS-NET: Addis Ababa.
- FEWS-NET. 2008. *Preliminary Rural Livelihoods Zoning: Tanzania*. FEWS-NET: Dar es Salaam.
- Gilligan, D., J. Hoddinott and A. Seyoum Taffesse. 2008. *The Impact of Ethiopia's Productive Safety Net Programme and its Linkages*. IFPRI Discussion Paper 00839. IFPRI.
- Haggblade, S., P. Hazell and T. Reardon. 2010. The rural non-farm economy: Prospects for growth and poverty reduction. *World Development* 38(10): 1429–1441.
- Haileslassie, A., J.A. Priess, E. Veldkamp and J.P. Lesschen. 2006. Smallholders' soil fertility management in the Central Highlands of Ethiopia: Implications for nutrient stocks, balances and sustainability of agroecosystems. *Nutrient Cycling in Agroecosystems* 75: 135–146.
- Hazell, P. 2011. Five big questions about five hundred million small farms. *Paper Presented at the IFAD Conference on New Directions for Smallholder Agriculture*, 24–25 January, 2011. IFAD.
- Headey, D., M. Dereje, J. Ricker-Gilbert, A. Josephson and A. Seyoum Taffesse. 2013. *Land Constraints and Agricultural Intensification in Ethiopia: A Village-Level Analysis of High-Potential Areas*. IFPRI Discussion Paper 01290. IFPRI.
- Hemp, A. and C. Hemp. 2009. Environment and worldview: The Chaga homegardens, part 1 – Ethnobotany and ethnozoology. In T. Clack (ed.) *Culture, History and Identity: Landscapes of Inhabitation in the Mount Kilimanjaro Area, Tanzania*. Archaeopress.
- Jaramillo J., E. Muchugu, F.R. Vega, A. Davis, C. Borgemeister et al. 2011. Some like it hot: The influence and implications of climate change on coffee berry borer (*Hypothenemus hampei*) and coffee production in east Africa. *PLoS ONE* 6(9): e24528. doi:10.1371/journal.pone.0024528.
- Jayne, T.S., J. Chamberlin and M. Muyanga. 2012. *Emerging Land Issues in African Agriculture: Implications for Food Security and Poverty Reduction Strategies*. Center on Food Security and the Environment. Stanford Symposium Series on Global Food Policy and Food Security in the 21st Century. Stanford University.
- Kaspersen, L.L. and T.H.Y. Foyen. 2010. *Price Transmission for Agricultural Commodities in Uganda: An Empirical Vector Autoregressive Analysis*. USSP Working Paper No 6. IFPRI.
- Kathiresan, A. 2011. *Strategies for Sustainable Crop Intensification in Rwanda: Shifting Focus from Producing Enough to Producing Surplus*. Ministry of Agriculture and Animal Resources, Republic of Rwanda.
- Keating, B.A., P.S. Carberry and J. Dixon. 2013. Agricultural intensification and the food security challenge in sub Saharan Africa. In B. Vanlauwe, P. van Asten and G. Blomme (eds) *Agro-Ecological Intensification of Agricultural Systems in the African Highlands*. Earthscan.
- Kibaara, B., J. Ariga, J. Olwande and T.S. Jayne. 2008. *Trends in Kenyan Agricultural Productivity 1997–2007*. Tegemeo Institute of Agricultural Policy and Development.
- Kimenju, S.C. and D. Tschirley. 2008. *Agriculture and Livelihood Diversification in Kenyan Rural Households*. Tegemeo Institute of Agricultural Policy and Development.
- Klapwijk, C.J., C. Bucagu, M.T. van Wijk, H.M.J. Udo, B. Vanlauwe, E. Munyanziza and K.E. Giller. 2014. The 'one cow per poor family' programme: Current and potential fodder availability within smallholder farming systems in southwest Rwanda. *Agricultural Systems* 131: 11–22.
- Kuhlmann, K., S. Sechler and J. Guinan. 2011. *Africa's Development Corridors as Pathways to Agricultural Development, Regional Economic Integration and Food Security in Africa*. The Aspen Institute.
- Liniger, H., J. Gikonyo, B. Kiteme and U. Wiesmann. 2005. Assessing and managing scarce tropical mountain water resources: The case of Mount Kenya and the semi-arid upper Ewaso Ng'iro Basin. *Mountain Research and Development* 25(2): 163–173.
- Losch, B., S. Fréguin-Gresh and E.T. White. 2012. *Structural Transformation and Rural Change Revisited: Challenges for Late Developing Countries in a Globalizing World*. African Development Forum Series. World Bank.

- Majule, A. 2010. The impact of land management practices on soil quality and implications on smallholder productivity in Southern Highland Tanzania. *Environmental Economics* 1(1): 59–67.
- Matsumoto, T. and T. Yamano. 2009. *Soil Fertility, Fertilizer and the Maize Green Revolution in East Africa*. Policy Research Working Paper 5158. World Bank.
- Minot, N. 2010. Staple food prices in Tanzania. *Paper for COMESA Policy Seminar: Variation in Staple Food Prices: Causes, Consequences and Policy Options*. Maputo, 25–26 January.
- Minten, B., D. Stifel and S. Tamru. 2012. *Structural Transformation in Ethiopia: Evidence from Cereal Markets*. IFPRI.
- Misana, S.B., C. Sokoni and M.J. Mbonile. 2012. Land-use/cover changes and their drivers on the slopes of Mount Kilimanjaro, Tanzania. *Journal of Geography and Regional Planning* 5(6): 151–164.
- Ndayambaje, J.D. 2013. Trees and woodlots in Rwanda and their role in fuelwood supply. Unpublished PhD Thesis. Wageningen University.
- Neven, D., M.M. Odera, T. Reardon and H. Wang. 2009. Kenyan supermarkets, emerging middle-class horticultural farmers, and employment impacts on the rural poor. *World Development* 37(11): 1802–1811.
- Okumu, M.O., P.J.A. van Asten, E. Kahangi, S.H. Okech, J. Jefwa and B. Vanlauwe. 2011. Production gradients in smallholder banana (cv. Giant Cavendish) farms in Central Kenya. *Scientia Horticulturae* 127: 475–481.
- Ouma, E. and J. Jagwe. 2010. Banana value chains in central Africa: Constraints and opportunities. *Paper Presented at the Joint 3rd African Association of Agricultural Economists Conference*, Cape Town, 19–23 September.
- Puhalla, J.M. 2009. Land use and agricultural intensification in Mugandu wetland, Kabale District, Uganda. PhD dissertation. University of Florida.
- Rao, E.J.O. and M. Qaim. 2010. Supermarkets, farm household income and poverty: Insights from Kenya. *Contributed Paper Presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference*, Cape Town, South Africa, 19–23 September.
- Ridley, F.V. 2010. The past and future climatic suitability of arabica coffee (*Coffea arabica* L.) in East Africa. MSc Thesis. University of Durham.
- Ruthenberg, H. 1971. *Farming Systems in the Tropics*. Oxford: Clarendon Press.
- Schmidt, E. and P. Dorosh. 2009. *A Sub-National Hunger Index for Ethiopia: Assessing Progress in Regional-Level Outcomes*. Discussion Paper No ESSP2 OO5. IFPRI.
- Schmidt, E. and M. Kedir. 2009. *Urbanization and Spatial Connectivity in Ethiopia: Urban Growth Analysis Using GIS*. ESSP II Working Paper 3. Addis Ababa, Ethiopia: International Food Policy Research Institute / Ethiopia Strategy Support Program II.
- Shreffler, K. and F. Nii-Amoo Doodoo. 2009. The role of intergenerational transfers, land, and education in fertility transition in rural Kenya: The case of Nyeri district. *Population and Environment* 30(3): 75–92.
- Stephens, E.C., C.F. Nicholson, D.R. Brown, D. Parsons, C.B. Barrett, J. Lehmann, D. Mbugua, S. Ngoze, A.N. Pell and S.J. Riha. 2012. Modeling the impact of natural resource-based poverty traps on food security in Kenya: The Crops, Livestock and Soils in Smallholder Economic Systems (CLASSES) model. *Food Security* 4: 423–439.
- Stern, D.I., P.W. Gething, C.W. Kabaria, W.H. Temperley, A.M. Noor et al. 2011. Temperature and malaria trends in highland east Africa. *PLoS ONE* 6(9): e24524. doi:10.1371/journal.pone.0024524.
- Taffesse, A.S., P. Dorosh and S. Asrat. 2011. *Crop Production in Ethiopia: Regional Patterns and Trends*. IFPRI.
- Tittonell, P. and K.E. Giller. 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research* 143: 76–90.
- Tittonell, P., B. Vanlauwe, P.A. Leffelaar, K.D. Shepherd and K.E. Giller. 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya. II: Within-farm

- variability in resource allocation, nutrient flows and soil fertility status. *Agriculture, Ecosystems and Environment* 110: 166–184.
- Wairegi, L.W.I. and P.J.A. Asten. 2010. The agronomic and economic benefits of fertilizer and mulch use in highland banana systems in Uganda. *Agricultural Systems* 108: 543–550.
- Waithaka, M.M., P.K. Thornton, M. Herrero and K.D. Shepherd. 2006. Bio-economic evaluation of farmers' perceptions of viable farms in western Kenya. *Agricultural Systems* 90: 243–271.
- Winter, J.C. 2009. Environment and worldview: The Chaga homegardens – part II: the social history of the Chagga in outline with special reference to the evolution of the homegardens. In T. Clack (ed.) *Culture, History and Identity: Landscapes of Inhabitation in the Mount Kilimanjaro Area, Tanzania*. Oxford: Archaeopress.
- World Bank. 2011. *Rwanda Economic Update: Seeds for Higher Growth, Spring Edition*. The World Bank.
- World Bank. 2015. Education Statistics (EdStat). <http://databank.worldbank.org/Data/Views/VariableSelection/SelectVariables.aspx?source=Education%20Statistics>.
- Yamano, T. and A. Arai. 2010. *The Maize Farm-Market Price Spread in Kenya and Uganda*. GRIPS Discussion Paper 10–25. Tokyo: National Graduate Institute for Policy Studies.
- Yamano, T. and Y. Kijima. 2010. *Market Access, Soil Fertility, and Income in East Africa*. GRIPS Discussion Papers 10–22. Tokyo: National Graduate Institute for Policy Studies.

6 The root and tuber crop farming system

Diversity, complexity and productivity potential

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Key messages

- The root and tuber crop farming system is a complex system found in humid and sub-humid areas of west and central Africa; it has mixed root and tuber crops (notably cassava and yam), some tree crops (e.g. oil palm, cocoa, rubber, cashew and mangoes) and cereals (e.g. rice, maize, sorghum and millet) but few livestock because of disease.
- The farming system is at an early stage of development, with an agricultural population of 50 million with an average farm size of 2.3 ha but with opportunity for expansion. Markets are generally poorly developed. Women play an important role in the farming system especially in the production and processing of root and tuber crops.
- In the long term, the system has high potential because of high biomass productivity with suitability for commercial tree crops, root and tuber crops (notably cassava) as well as horticulture, and proximity to major urban centres and export ports.
- Strategic priorities for the sector include market-oriented intensification through the use of improved varieties and integrated soil fertility management, complemented by diversification to include cereals, legumes, ruminants and improved processing options for root and tuber crops.
- Such intensification and diversification requires farmer training, increased research and extension capacity, investment in transport and market infrastructure, and national policies that promote roots and tubers as both food security and industrial crops supported by public-private partnerships.

Summary

The root and tuber crop farming system occurs in west and central Africa, bounded on the southern, wetter side by the tree crop farming system and on the northern, drier side by the cereal-root crop mixed farming system. The root and tuber crop farming system occupies an estimated 236 million ha and has an estimated human population of 112 million, of whom over 50 per cent live in rural areas. Poverty is relatively high with about half the rural population earning less than US\$1.25 per day.

The system has a humid tropical climate with, on average, a nine-month growing season. These climatic conditions support the characteristic root and tuber crops

(cassava, cocoyam, yam and sweet potatoes) complemented by some tree crops (oil palm, cocoa, rubber, cashew and mangoes) and cereals (maize, rice, sorghum and millet) and small numbers of livestock – making it a highly diverse and complex farming system with stable and relatively high potential food productivity.

The farming system is at an early stage of development, mainly focused on household food security. Markets are generally poorly developed, although there are pockets of semi-commercial farming. Total cultivated area is nearly 23 million ha, of which little is irrigated. Farm sizes are generally small, usually less than 2 ha. Crop production is mostly subsistence. Female members of farm households have an important role in the farming system, especially in the production and processing of root and tuber crops.

The farming system has great potential because of its high biomass productivity combined with its suitability for commercial tree crops, root and tuber crops as well as horticulture, and proximity to major urban centres and export ports. In coming years, the system is expected to expand production of tree, root and tuber crops to meet the food needs of a rapidly increasing urban population. Increased productivity requires wider use of high-yielding crop varieties coupled with integrated soil fertility management (ISFM) to replenish declining soil fertility. Strategic priorities for the sector include market-oriented intensification through the use of improved varieties and ISFM technologies, complemented by diversification to include cereals, other annual crops and ruminant production. This intensification and diversification requires farmer training, increased research and extension capacity, investment in transport and market infrastructure, and national policies that promote roots and tubers as both food security and industrial crops supported by public-private partnerships.

Introduction

The root and tuber crop farming system is a traditional farming system of the wet humid forest and the forest-savannah transitional agroecological zones in west and central Africa. Based originally on yams and cocoyams, the system was enriched with the introduction of cassava from Brazil and more recently with grain crops brought by migrants from the cereal-root crop mixed farming system. Parts of the system can be found in 13 countries across west and central Africa, including Sierra Leone, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, Cameroon, Central African Republic, Gabon, the Republic of Congo, Democratic Republic of Congo (DRC), Angola and Tanzania. The farming population is ethnically diverse, especially within the western part of the system due to immigrants from the cereal-root crop and the agropastoral farming system in the north.

The traditional nature of the system stands in marked contrast to the commercialization of the tree crop farming system to the south and the crop-livestock integration in the cereal-root crop mixed farming system to the north. While there are pockets of commercialization, for example of tree crops, there are also areas that have reverted from commercial tree crops to traditional food crop-based farming, for example in Ghana following the disastrous bushfires in 1983 that were followed by drought.

Overview of the farming system and subsystems

Key characteristics

The root and tuber crop farming system occupies a total estimated area of 236 million ha, and supports about 112 million people, of whom 60 million live in the rural

Table 6.1 Basic system data (2015): root and tuber crop farming system

<i>Farming system descriptor</i>	<i>Data</i>
Total human population (million)	112
Agricultural population (million)	50
Total system area (million ha)	236
Cultivated area (million ha; % of total area)	22.5; 10
Irrigated area (million ha; % of cultivated area)	0.15; 1
Total livestock population (million TLU)	8
Major agroecological zone	Tropical warm humid
Length of growing period (average and core LGP range, days)	269; 210–300
Access to services (low/medium/high)	Medium
Distance to 50k market (average, hr: core range, hr)	8.8; 4–10+
Agricultural population density (persons/total ha; persons/cultivated ha)	0.2; 2.2
Livestock density (TLU/total ha; TLU/cultivated ha)	0.03; 0.4
Standard farm/herd size (cultivated ha/household, TLU/household)	2.5; 0.9
Extreme poverty (% of rural population)	54

Source: Refer to Table 2.4.

areas and 51 million are agricultural (Table 6.1). Population growth is high and extreme poverty is relatively high; about half the rural population live on less than US\$1.25 per day.

The characteristic crops are yams, cocoyams and cassava, but increasing areas of rice, maize, sorghum, millet and bambara nuts are grown especially in the northern parts of the system. Traditional vegetables and spices are common but not generally produced on a commercial scale. Because of the length of growing season (average LGP 269 days) and high temperatures, potential biomass productivity is high. In part because of trypanosomiasis, cattle numbers are low but there are moderate numbers of goats (approximately 13 million), pigs (7 million) and poultry (98 million). These livestock and poultry are not well integrated into the farming system.

Despite the agricultural potential, the current access to agricultural services varies from poor to moderate, with only a modest portion of production being marketed – typically cassava and some tree crop products.

Biophysical characteristics of the farming system

The farming system receives 1000–2500 mm annual rainfall distributed in a bimodal pattern in the northern, drier, forest-savanna agroecological zone, and in a continuous rainfall pattern in the southern, wetter, forest agroecological zone. Due to the long growing period, risk of crop failure from drought is low. The humid and sub-humid tropical climatic conditions are associated not only with high biomass productivity but also with high biotic stress on plant and animal production. There is a wide variety of soils. With increasing population pressure, deforestation and land degradation are increasing. The influence of the north-south climatic and edaphic gradations on cropping and livestock is discussed later.

The characteristic root and tuber crops cultivated in the farming system are cassava (*Manihot esculenta*), yams (*Dioscorea* spp.), cocoyams (*Xanthosoma* spp.), sweet potato (*Ipomoea batatas*) and potato (*Solanum tuberosum*). Farmers cultivate these crops on about 47 per cent of the typical farm. (These same root and tuber crops are found in other African farming systems, but often play more modest roles.) Within the root and tuber crop farming system, other important sources of farm livelihoods include maize (*Zea mays*), rice (*Oriza sativa*) and off-farm income sources such as trading, craft and salaried work. Some farmers produce small areas of groundnut, sugarcane, coffee, cocoa, sorghum, ginger, cowpea and bambara nut, and also vegetables (eggplant, pepper), plantain, banana, ben-nised (sesame) and citrus in some places.

Urban dwellers increasingly prefer potato and sweet potato as a result of the rapidly increasing number of fast food industries and hotels. Because of their short duration to produce, these crops are very strategic for mitigating food crises. However, the most dynamic crop of this system is cassava, for which production has doubled or tripled in some countries since the late 1990s as a food security, commercial and industrial crop. It fits flexibly into many farming systems, with a range of planting and harvesting dates, and can be stored in the ground for many months (up to three years) before harvesting. Households can consume cassava processed as human food, or as a variety of convenience foods. Cassava can also be processed for use as animal feeds or industrial products. Yam production is concentrated in the savannah regions of West Africa where more than 90 per cent of the crop is grown. The white and yellow yams (*Dioscorea rotundata* and *D. cayenensis* respectively) are believed to be indigenous to west Africa whereas the water yam (*D. alata*) is believed to have originated in South East Asia (O'Sullivan 2010). Cocoyams constitute a staple food in some parts of Ghana, Cameroon and Gabon. In Nigeria, cocoyam is grown as secondary crop and ranks far behind yam and cassava. Cocoyams are often grown in association with tree crops, particularly cocoa.

Farmers also cultivate a range of cereals (rice, maize, sorghum and millet), which occupy about 28 per cent of the harvested area. Rice has expanded recently, and maize became a major crop in the farming system from the 1970s onwards, based on new maize germplasm – both crops benefited from the development of rural roads and strong urban demand (Badu Apraku et al. 2003). Recently, farmers have produced maize instead of sorghum and millet because maize is now consumed (instead of these cereals) in some local dishes. Rice has expanded in the farming system as a result of adoption of new and improved varieties but most importantly through area expansion ('extensification'), particularly the valley bottoms. A large proportion of the rainfed lowland rice grown in western Africa occurs in this farming system.

Despite a high potential for livestock production due to availability of forage and grasses, few farmers keep livestock. In areas close to major inland waterways, particularly rivers, fishing is common. The transitional nature of the agroecosystems and the ethnic and cultural diversity resulting from immigration have led to considerable local diversity in the cropping pattern.

Farmers allocate a significant portion of their farm to root and tuber crops particularly cassava, yams and sweet potatoes (Figure 6.1) because of their broad agroecological adaptability as well as their adaptation to marginal environments, greater flexibility in mixed cropping systems, ability to produce reasonable yields where most crops cannot and their capacity to provide a large quantity of carbohydrate. Cereals, notably rice and maize, are

Figure 6.1 Relative importance of food crops by harvested area in the root and tuber crop farming system.

Source: FAOSTAT, Harvest Choice.

Note: SPY = sweet potato and yams.

expanding; and pulses and groundnuts are also significant crops. In addition, tree crops augment the livelihoods in some parts of the farming system – although not such a dominant feature as in the tree crop farming system.

As well as being a source of cash income for smallholder farmers in rural areas, root and tuber crops are an important component of food security in both rural and urban areas. Root and tuber crops contribute about 20 per cent of the daily per capita calorie intake for households. Each major crop or animal type plays a specific role in the farming system and makes a unique contribution to household livelihoods. The following paragraphs describe the roles of the major crops and animals in the farming system (compared with the wider context in Africa) and some key aspects of the resulting farming system.

Cassava

Approximately 30 per cent of all cassava grown and marketed in Africa is cultivated in the root and tuber crop farming system. It is the most important food staple in nearly two-thirds of the countries in Africa. Production is by smallholder farmers, a significant percentage being women. Farmers use virtually no mineral fertilizer, and soil nutrients

removed in the root harvest are seldom replenished. As a result, farmers obtain an average yield of 8 t/ha⁻¹ (Tittonell and Giller 2013) compared with attainable yields of about 35 t/ha⁻¹. Furthermore, farmers use inadequate cultural practices, especially poor-quality planting material and sub-optimal plant densities, and are confronted with serious weed, pest and disease problems. Currently, the majority of cultivated varieties are susceptible to pests and diseases causing significant yield losses (Akinbade et al. 2010). Cassava root is consumed in many forms particularly fresh, boiled or processed, but its leaves also serve as vegetables, and cassava is largely grown as an intercrop by smallholder farmers (Figure 6.2) (Agwu and Anyaeche 2007). In Cameroon, smallholder producers and consumers have marked preferences for specific varieties, and these determine the uptake of new varieties. Early-maturing and high-yielding varieties have become more important where there is pressure on land and farmers want to intensify production (Kamau et al. 2011), coupled with surging demand for raw materials for the food, feed, starch, ethanol and biofuel industries. Consequently, there are two quite distinct roles for cassava in African farming systems: as a flexible, food security reserve that is stored in-ground, especially in drought prone areas, and as a cash crop for food, feed and bioethanol, especially in west Africa. The cassava processing industry (for the food product gari and starch) is well developed in west Africa in general (e.g. Nigeria and Ghana) and in pockets of the root and tuber crop farming system.

Figure 6.2 Maize-cassava intercropping system in Ibadan, southwestern Nigeria. Farmers benefit from the slow early growth of cassava to raise another crop before the cassava canopy closes. Maize is grown for only the first three months in a one-year cassava cycle.

Source: Stefan Hauser.

Yam and cocoyam

These tuber crops are grown widely across sub-Saharan Africa. Consequently, the root and tuber crop farming system accounts for only 23 per cent of all yam grown and marketed in Africa, concentrated in West Africa where yams are an integral part of the farming system. Yams are estimated to provide more than 200 dietary calories each day for over 60 million people. Important yam-producing countries within the farming system include Nigeria, Ghana, Côte d'Ivoire, Benin and Togo. The total fresh tuber production of yams in Nigeria is estimated to be 33 million tonnes per year, giving a national average tuber yield of 13 t/ha (NAELS 2009) – where 90 per cent of farmers are smallholders who mostly use manual labour and cultivate 0.8–1.2 ha in the forest areas (of the root and tuber crop farming system) and 2–4 ha in the savannah (of the cereal-root crop mixed farming system). Most yam production occurs in the savannah and the forest-savannah transition zones in just 14 states that account for 82 per cent of the national yam area. These farmers also reserve a good proportion of the harvest for planting in the following season (Asumugha et al. 2009).

In spite of the economic and sociocultural importance of yams, production is constrained by limited availability and cost of planting material, as well as susceptibility to a variety of pests and diseases during growth as well as post-harvest (IITA 2012). Yams are affected by insects, nematodes, vertebrate pests, fungal and bacterial diseases, and viruses which, either singly or in combination, are responsible for low yields and deterioration in the quality of the tubers in storage. The International Institute of Tropical Agriculture (IITA) in collaboration with the National Root Crops Research Institute (NRCRI) of Nigeria has produced and distributed a large number of improved varieties that are under release-track evaluation in many countries in west Africa.

Cocoyam is another important component of the root and tuber crop farming system in Ghana, Nigeria and Cameroon. Cocoyam ranks second to cassava for dietary energy in Cameroon (PNDRT 2005). Farmers cultivate cocoyam for both starchy tubers, which are boiled or processed, and its leaves, which serve as vegetables.

Sweet potato and potato

Sweet potato also plays an important role in the diet of many Africans especially in Burundi, Tanzania, Nigeria and Angola. It is a good source of energy, calcium and iron, and is nutritionally rich in vitamins and minerals with a higher carotene content than other root and tuber crops. The orange-fleshed sweet potato varieties are a rich source of pro-vitamin A and beta-carotene, which help to prevent the debilitating diseases caused by vitamin A deficiency in children. Sweet potato is the fourth most important root and tuber crop in Nigeria (Islam et al. 2000). The major constraints to sweet potato production are inappropriate agronomic practices, degeneration of older varieties, low output prices and high incidence of pests (notably the weevil *Cylas puncticollis*, in the dry season) and diseases (including sweet potato virus diseases (SPVD), chlorosis, vein banding, stunting and mosaic or mottle diseases, as well as fungal diseases such as leaf spot (which is endemic throughout Africa), root rot occasioned by *Pisobus* and *Penicillium* spp., and black rot caused by *Macrophomina phaseoli*). In Nigeria, farmers cultivate sweet potato predominantly as a monocrop in the northern part of the farming system but generally as an intercrop with other arable crops in the southern areas of the system.

Potato is a minor but important crop in parts of the farming system in East Africa, particularly Rwanda, Burundi, Uganda and Tanzania. While sweet potato is an important staple crop in the densely populated, intensively cultivated mid-altitude areas, potato is an important food and cash crop in the highlands. In other farming systems in East Africa, potato production is growing faster than major root crops and cereals. Yields are low due to several factors including lack of good quality improved varieties, sub-optimal crop management practices and poor access to market. Most of the potato is consumed directly, mainly boiled. However, with increasing population and rapid urbanization, consumption preferences are changing rapidly in favour of easy-to-prepare foods such as chips.

Tree crops

Tree crops play an important role in parts of the farming system. In the more humid, low altitude zones the major tree crops include oil palm, cocoa and rubber, commonly intercropped with cassava and cocoyam until the tree canopy closes. In the sub-humid areas of the farming system, cashew and mangoes are important. The indigenous borassus palm (*Borassus aethiopum*) and dawadawa (African locust bean tree *Parkia biglobosa*) are also important sources of cash livelihoods. The fruits of borassus are an important food security crop in the forest-savannah transition zone. Dawadawa fruits are processed by women and used as a spice in the preparation of several dishes in west Africa. Sometimes yams and cassava are planted under tree canopies. In high altitude regions, coffee is the most important tree crop.

Livestock, fish and poultry

Potential areas for livestock development include small ruminants because of the availability of forage, and pigs for consumption and cash income. However currently, most households only own one ruminant and some chickens. The current livestock density is 0.03 tropical livestock units (TLU)/ha of land or 0.4 TLU/ha cultivated land (Table 6.1) – about one-quarter of the average livestock densities across Africa of 0.11 and 1.29 TLU/ha respectively. Pigs account for 22 per cent of the total TLU (compared with 19 per cent in the neighbouring tree crop system and an average of 4 per cent across all African farming systems). Cattle account for 60 per cent of the livestock, lower than in most African systems. Problems associated with livestock production include prevalence of livestock diseases and tsetse flies, conflicts with crop farmers and cultural taboos which prohibit the rearing of some animals, particularly goats and pigs. River and lake fishing is prevalent especially in the northern areas.

System patterns and linkages

As noted earlier, cropping and livestock patterns vary between the humid forest agroecological zone in the south and the drier forest-savannah transitional agroecological zone in the north and the east (Boxes 6.1 and 6.2). The humid forest zone cropping is dominated by cassava, maize, rice, sugar cane and beans produced with limited mechanization; cash livelihoods are dominated by cassava and rice sales, off-farm work and trading. There are many similarities with the tree crop farming system. A different cropping pattern dominates the drier forest-savannah transitional (sub-humid) zone, with yam, cassava, cocoyam,

legumes, maize, rice and cashew with significant mechanization and external inputs; cash livelihoods are dominated by yam, cassava, maize, livestock and fishing. It is notable that livestock are relatively domiciled in the northern areas, consistent with the nearby cereal-root crop mixed farming system with mechanized, integrated crop-livestock patterns.

Nutrients and machinery

Farmers often intercrop cassava, yams and maize in a relay cropping system. First, yam is planted after land preparation, followed by maize and then cassava. Maize is also often rotated with cassava or legumes such as groundnut and cowpea, especially in the sub-humid zone where high population density co-exists with mechanization and farmers often plant maize twice a year. In most parts of the system, including Ghana and Benin (and also some parts of eastern Africa), rotation with cassava is used as a strategy for regenerating soil fertility (Adjei-Nsiah et al. 2004; Fermont 2006; Saïdou et al. 2004). Only 20 per cent of farmers use fertilizer, mainly on the maize crop.

Cassava regenerates soil fertility by recycling lost nutrients from litter fall found deeper in the soil profile, and through contributing harvested leafy biomass into the soil after harvest. In the past when land was abundant and population was low, bush fallowing was the means by which farmers replenished the soil. Further south where the land is more fertile (which attracted many immigrants from the cereal-root crop mixed and agropastoral farming systems), continuous cropping has replaced the bush fallowing system. However, continuous cropping practised without the application of nutrients or mineral fertilizer is leading to a rapid decline in soil fertility and low crop yields.

Agricultural mechanization is not well developed in the farming system except in the forest-savannah transitional zones of west Africa, where cultivation of maize is intense and the continuous use of tractors for land preparation has resulted in widespread land degradation. In the more humid parts, cutlass and hoe remain the most important tools for cultivation. This restricts the land area that a farmer can cultivate. Farmers generally rely on planting materials from their own or neighbouring farms, selecting agronomic traits such as taste, early maturity, good processing qualities, yield, and pest and disease resistance (Lulombo et al. 2002; Soro et al. 2010).

Socioeconomic characteristics: ethnicity, gender and land tenure

The population of the farming system is ethnically diverse, resulting from immigration from the north, attracted by the prospects of better farming livelihoods given the favourable climatic conditions and available fertile land. Typical household characteristics in two different areas of the root and tuber crop farming system are described in Boxes 6.1 and 6.2. While population density declines from the wetter forest zone in the south to the drier forest-savannah zone in the north, average population density in the system is 0.2 persons per ha and 2.2 persons per ha of cultivated land.

In some parts of the farming system, such as Sierra Leone, land is held under customary tenure and is controlled by traditional rulers who administer it on behalf of the communities (Asamoah Larbi 2012). The land tenure arrangements in most parts of the farming system make it difficult for women and other vulnerable groups such as migrants and youth, to access land or to invest in its improvement. Also, because of the ambiguity in land tenure, there are often land disputes among landowners and tenant farmers. Immigration has resulted in a spectrum of land tenure arrangements ranging from rights acquired by

being a member of a landowning family, to renting or sharecropping. Migrants cannot own land in this zone, and they mainly access land for farming purposes through renting, as in Benin, or sharecropping or taungya (a system where the state gives land to farmers to grow food crops while planting and tending trees for the state) as is practised in Ghana (Saïdou et al. 2007). In Nigeria, land tenure is mainly by leasing.

Box 6.1 A typical household of the forest-savannah transitional zone of the root and tuber crop farming system, Ghana

A typical household in the root and tuber crop farming system in Ghana's forest-savannah transitional zone has between six and eight persons consisting of the household head with one wife, a few children and one or two members from the extended family. The household allocates about 80 per cent of their farmland to the cultivation of maize, cassava and yam. These are the most important crops in the system, and few farmers cultivate other crops such as cocoyam, plantain, cashew, groundnut, cowpea and mangoes. Cassava and maize are the main food and cash crops respectively and yams fill both functions. Hoe and cutlass are used for crop production. The farm uses fertilizer, but only on the maize crop. The household owns one small ruminant and some chickens. Roots and tubers are the main on-farm income. Off-farm sources of income include salaried work, trading, selling of labour and remittances. The household lives in a hamlet, but there is poor infrastructure including roads, schools, market and health facilities. While they have food, the household is vulnerable to changing climatic conditions due to lack of resources.

Most male farmers cultivate maize as their main on-farm income, while in the less humid zone yam serves as the main source of on-farm income. In Ghana, especially in the forest-savannah transitional zone, maize is exclusively cultivated by male farmers while women cultivate root crops, particularly cassava and yams which require fewer external inputs (Adjei-Nsiah et al. 2007). Roots and tubers are the main source of on-farm income for female farmers, most of whom (90 per cent) manage less than a hectare of land. Female farmers perceive maize cultivation as a risky farm enterprise due to its sensitivity to drought. The focus on root crops, particularly cassava, can be an ex-ante risk management strategy (Devereux 2001) because of their drought tolerance and flexible planting and harvesting periods, which enables flexible substitution of foods according to seasonal conditions.

Smallholders often rely on social networks for exchange of skills and labour to help adapt to changing climatic conditions. For instance in Wenchi, migrant farmers who have low human and financial capital rely on reciprocal labour to help maintain and sustain their productivity. Hence, they tend to be vulnerable to changing climatic conditions as the capacity of any social group to adapt to climate change and variability depends on their physical location, entitlements to land and access to knowledge and education.

Female farmers constitute 49 per cent of the economically active agricultural population (excluding young girls and aged women). In most areas within the farming system, decisions regarding land use are made by the household heads, who are usually men.

Among the Akans of Ghana, husbands and wives may farm independently, although they may collaborate in several ways such as sharing of labour. However, among migrants, especially those of northern origin, women do not have their own farm enterprises except in the case of widows.

Women are involved not only in the production of roots and tubers but also in the distribution, retailing and processing of the crops, particularly cassava (Figure 6.3), and are a critical source of production and processing practice knowledge. According to Nweke et al. (2002), in Nigeria females provide most of the labour in cassava production. Because of the lack of access to credit, rural women practise communal farming to reduce the cost of production.

Box 6.2 A typical household of the root and tuber crop farming system in south-eastern Nigeria

In the root and tuber crop farming system in south-eastern Nigeria, households live in scattered rural villages. Household size is about nine persons consisting of a husband (usually the household head), wife and an average of seven children based on the need for family labour in subsistence farming. The household cultivates less than 2 ha at subsistence level, and grows maize, cassava, yam, cocoyam, vegetables, melon, sweet potato and cowpea. Average yields of the major crops, yam and cassava, are about 13 t/ha grown under farmers' conditions, although with improved varieties and recommended practices, the yield could increase to 35 t/ha. Cassava and yam are sometimes intercropped with maize, cowpea and vegetables or planted as sole crops. Mechanization is still rudimentary. Traditional systems with hoes and machetes are still popular. Livestock such as goats, sheep and local chickens are kept mostly for cash to solve household immediate needs. Most women engage in trading as a supplementary source of income. Off-farm income from sources including trading, salaried work, arts and crafts constitutes a major component of household livelihoods.

Although livestock is not an important source of livelihoods in the farming system, in recent times, the influx of nomadic Fulani with their cattle into the west African portion of the farming system has brought conflict between the farmers and the nomadic Fulani (Ofuoku and Isife 2009). The cause of such conflicts includes destruction of crops, contamination of streams by cattle, disregard for local traditions, female harassment and harassment of nomads by youths of host communities. Nomads regard their movement from place to place as a way of life and few are settled, the conflicts with farmers notwithstanding. This is a complex situation and the answers continue to be elusive. The issue centres on whether the Fulani cattle herdsman will settle and engage in integrated crop-livestock farming. With settled life, extension agencies promote integrated crop-livestock farming.

Subsystems

The farming system experiences a range of climatic conditions because it cuts across three agroecological zones, namely the forest, forest-savannah transitional and the guinea

Figure 6.3 Women processing cassava.

Source: Samuel Adjei-Nsiah.

savannah zones. Thus, the characteristic root and tuber crop pattern is supplemented by cereal, legume, tree and oil crops.

Five main subsystems can be identified based on the dominant crop mixes, and the associated enterprise patterns (Table 6.2, Figure 6.4), as follows:

- yam–cassava subsystem
- cassava subsystem
- cassava–cocoyam subsystem
- cassava–sweet potato–potato subsystem
- cassava–yam–cocoyam subsystem.

The subsystem name is based on the dominant root and tuber crop(s) in addition to cassava (which forms a major component within all the subsystems). Note that cereals, legumes and tree crops also occur in the systems. Despite the apparent similarity of the subsystem names, the subsystems are distinct, as outlined below and in Table 6.2. Figure 6.4 shows the distribution of the subsystems across west and central Africa.

The cassava-based subsystem is found in Guinea, Sierra Leone, DRC, Gabon and Congo. Rainfall is bimodal to continuous and exceeds 1500 mm per annum. The vegetation is predominantly lowland rainforest. Cassava, maize, sugar cane, rice, melon, vegetables, plantain and beans are the major crops grown in this subsystem. In the South Kivu province of DRC,

Figure 6.4 Extent of the root and tuber crop farming subsystems in Africa.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

cassava and common beans are among the main food crops cultivated in mixed cropping systems. Farmers generally allocate 0.2–0.3 ha (30–45 per cent of their farm area) to cassava-legume intercropping and obtain an average yield of 10–15 t/ha. In the less populated area of Ba-Congo province, farmers practise slash and burn agriculture. Cassava is grown for one or two years, followed by fallow periods of two to four years (Vanlauwe et al. 2013).

The cassava-cocoyam subsystem is found in Cameroon and apart from lower rainfall, has similar agroecological conditions to the cassava-based subsystem (Table 6.2). Important tree crops in the cassava-cocoyam subsystem are cocoa and oil palm. The vegetation is lowland forest with rainfall of about 1200 to 1500 mm per annum. Cocoyam features prominently in this system.

The cassava-sweet potato-potato subsystem is found in South Sudan, Burundi, Tanzania and Angola in low to high altitudes areas. Rainfall within this subsystem ranges from 1000–1500 mm per annum. While cassava and sweet potatoes are cultivated in low to mid altitudes areas with 1200–1300 mm rainfall, potato is usually grown in high altitudes areas with less than 1200 mm. Population density within this subsystem is high. Average farm size is extremely small, less than a hectare. Use of external inputs within this subsystem is limited and mechanization is largely absent.

The yam-cassava and the cassava-yam-cocoyam subsystems stretch from Côte d'Ivoire in the west to Nigeria and Central African Republic (CAR) in the east. The two subsystems lie within the same agroecological zone, but cocoyam does not feature as strongly in the yam-cassava subsystem due to dietary culture and food preferences. The two subsystems have aspects of the semi-deciduous forest and guinea savannah vegetation. In the forest-savannah transitional and guinea savannah zones of these subsystems, the vegetation is dominated by tall grasses especially *Pennisetum purpureum* and *Panicum maximum* with scattered trees and shrubs. These subsystems have substantial crop diversity (Table 6.2).

Table 6.2 Key characteristics of the root and tuber crop farming subsystems

<i>Subsystem</i>	<i>Countries</i>	<i>Market access</i>	<i>Subsystem characteristics</i>	<i>Major crops</i>	<i>Rainfall; altitude</i>	<i>Major livelihoods</i>
Yam-cassava-based	Côte d'Ivoire, Benin, Togo, CAR	Medium-high	Limited mechanization, minimal external inputs, livestock important	Yams, cassava, legumes, cashew, maize, upland rice	Bimodal, 1200–1400 mm; altitude-low	Yams, livestock, fishing
Cassava-yam-cocoyam-based	Ghana, Nigeria	Medium-high	Medium use of tractors, high use of external inputs	Cassava, maize, yam, cocoyam, legumes, plantain, cashew, mangoes	Bimodal, 1200–1500 mm; altitude-low	Roots and tubers, maize, off-farm income, trading
Cassava-cocoyam-based	Cameroon	Low	Limited mechanization, minimal use of external inputs	Cassava, maize, sugarcane, cocoyam	Bimodal, 1200–1500 mm; altitude-low	Cassava, maize, off-farm income
Cassava-sweet potato-potato-based	South Sudan, Burundi, Angola, Tanzania	Medium	Limited mechanization, limited use of external inputs	Sweet potato, cassava, banana, maize	Bimodal, 1000–1300 mm; altitude-medium to high	Roots and tubers, off-farm income
Cassava-based	DRC, Congo, Guinea, Sierra Leone, Gabon	Low	Limited mechanization, limited use of external input	Cassava, maize, legumes, sugarcane, rice	Bimodal to continuous, 1200–2500 mm; altitude-low	Cassava, off-farm income

Trends and drivers of change

It is worth noting that the majority of the crops in this farming system did not originate in Africa. Cassava was first introduced into the Congo by the Portuguese traders in 1550. The crop expanded during the colonial times to prevent food shortage. Potato, sweet potato and cocoyams originated in Latin America. Similarly cattle, sheep, goats and pigs are introduced species. The current farming system has evolved massively from the traditional systems prevalent in previous centuries, as a consequence of various forces.

Much of the root and tuber crop farming system used to be part of the tree crop farming system. For instance in Ghana, this used to be a major cocoa-growing area in the early 1940s. The abundant land attracted migrants to cultivate cocoa or work as farm labourers in cocoa farms. However, the 1982–83 bushfires across Ghana destroyed much of the cocoa, which failed to be re-established, so farmers shifted to food crop production as an adaptation strategy (Donatelli et al. 2000). Farmers resorted to cultivation of maize, yam and cassava, which have lower moisture requirements than cocoa. According to farmers in this zone, widespread cassava production in this zone is recent and expanded with increasing drought frequency.

The development of industries based on food commodities generally passes through several recognizable phases: minor (sometimes new) supplementary food crop; rural food staple; cash crop for urban consumption and export; and, finally, an input to industrial processing. From this perspective, the cassava industry in the root and tuber crop farming system is fairly well developed, with supply chains for animal feed, starch and bioenergy (Nweke et al. 2002). Maize has passed through the third phase and is entering the industrial phase with significant demand from the poultry feed industry. The following sections address drivers affecting the current farming system (see also Table 6.3).

Population, poverty and hunger

Between 2000 and 2010, the agricultural population in the farming system increased by 19 per cent while the population of females active in agriculture increased by about 22 per cent. The urban population increased from 31 million in 2000 to almost 49 million in 2015, an increase of more than 60 per cent. This means that more people in cities and towns will buy food instead of growing it themselves. Demand for root crops is expected to increase rapidly to meet the food needs of the urban population, providing smallholder farmers with a source of cash income from roots and tubers, particularly cassava. Resulting gains in poverty reduction and greater food security will, however, depend partly on the dissemination and adoption of improved practices that include higher-yielding pest-resistant varieties; improved crop management and processing equipment and procedures; and better linkages among producers, processors and consumers. Currently, limited technology uptake has resulted in expansion of cropped areas, sometimes on marginal lands, and a decline in labour productivity. As described earlier, urban and rural food preferences now favour rice and maize rather than traditional grains. A reduction in poverty would accentuate such a preference shift, with further consequences for the cropping patterns – favouring rice, maize and cassava food crops.

Natural resource and climate

The quest for fertile land for the cultivation of root crops, particularly cocoyam, yam and trees to stake yam, has resulted in loss of biodiversity from most environments in the forest-savannah transitional agroecological zone. The expansion of agricultural land

reduces forest cover and biodiversity (Hilderink et al. 2012). Tree removal for charcoal production, removal of forest cover to allow crop production, and improper farming practices such as bush burning coupled with shortened fallow due to population pressure, have resulted in widespread land degradation and loss of biodiversity in most of the root and tuber crop zones (Adjei et al. 2003). The impacts have been exacerbated by lack of appropriate soil fertility management practices.

Declining rainfall patterns and soil fertility have also resulted in declining production in certain root crops, particularly cocoyam and yam which require more fertile soils. As yields decline, farmers tend to expand their farm size to compensate for reduced yield. Cassava thrives well in areas where other crops fail, and root crop production has been used as a strategy for adapting to climate change and variability (Adjei-Nsiah et al. 2010).

The predicted climate change scenario suggests an increase in temperature with declining yields of root and tuber crops, with the rate of reduction increasing with time or with a rise in temperature and solar radiation (Agyemang-Bonsu et al. 2008). Unless production practices are changed, productivity or yield of cassava is expected to reduce by 3, 13.5 and 53 per cent by the years 2020, 2050 and 2080 respectively. Cocoyam productivity is predicted to decline by 11.8, 29.6 and 68 per cent by 2020, 2050 and 2080 respectively (Agyemang-Bonsu et al. 2008). Clearly, climate-smart agricultural practices must be an important element of future farming systems.

Energy

Biomass energy represents a large proportion of total energy use in the farming system, mostly for cooking and heating of water by households. Furthermore, most poor households in the farming system sell firewood or charcoal to supplement their livelihoods from crop sales. Charcoal production and annual bush fires reduce tree cover and undermine the sustainability of the farming system. Tree removal for charcoal production exposes the soil to erosion and loss of soil organic matter resulting in widespread soil degradation. For instance in Tanzania where over 90 per cent of households use charcoal as their primary source of fuel, traditional charcoal production has led to severe deforestation, causing environmental stress and degradation, diminishing watershed management and increasing vulnerability to climate change.

Recent high energy prices have tended to contribute to deforestation and land degradation activities through greater use of wood and charcoal in rural and urban areas. The recent, high cost of fossil fuel has also resulted in increased production costs in areas where tractor mechanization is practised.

Ambitious plans exist for grid-based rural electrification (APP 2015), but many observers expect local mini-grids based on renewable energy (solar, wind, water and bioenergy) to play an important interim role pending full electrification. Langeveld et al. (2015) provide an analysis of the most promising bioenergy options. It is expected that fossil fuels will remain important for transportation, which is critical for access to services and markets, and for mechanization of production in the foreseeable future (although there are promising renewable-based technologies in use for water pumping, and emerging for tractive power).

Sociocultural norms, human capital and gender

In most farming communities in the system, gender inequalities preclude most women from accessing land and agricultural credit (Byamugisha 2013), although studies have shown that women are often credit worthy (Jones and Sakyi-Dawson 2001). As noted

earlier, land is generally passed to successive generations through the male line of descent. For example, in areas from Sierra Leone through Benin to the south-eastern and mid-dle belts of Nigeria, when a man dies without a son, his land is passed on to his brothers even if he has daughters. These factors tend to mean African women have less access to productive resources than men, and produce less. For example in Ghana, women farmers produce 17 per cent less than their male counterparts (FAO 2011; World Bank 2011). While traditional yam festivals tend to promote yam production, high illiteracy rates tend to adversely affect technology adoption and use.

Science and technology

During the 2010s, research by scientists at the International Institute of Tropical Agriculture (IITA) and National Agricultural Research System (NARS) in some of the cassava-producing countries including Ghana, Benin, Nigeria and Cameroon, has resulted in successful control of most cassava diseases, particularly cassava mosaic disease (CMD). This has been achieved through incorporation of resistant genes into high-yielding cassava varieties. IITA in collaboration with NARS has evaluated and promoted high-yielding, disease-resistant varieties that have increased productivity of cassava in the farming system. Most of these varieties, which yield between 20–30 t/ha, have replaced the late-maturing, low-yielding varieties.

In Cameroon, five Tropical Manioc Selection (TMS) cassava varieties: (92/0057, 92/0067, 92/0326, 96/0023 and 96/1414) have been selected and promoted on the basis of their high root yield (>20 t/ha), high dry matter content (>35 per cent) and high CMD resistance. These varieties are being promoted through a three-tier multiplication scheme (primary, secondary and tertiary) to ensure equitable, fast and sustainable distribution of healthy planting materials, through two projects funded by the International Fund for Agricultural Development. Programme National de Développement des Racines et Tubercules (PNDR) implemented by the government of Cameroon, and Cassava Integrated Pest Management (IPM) implemented by IITA.

In Ghana, the production of major root crops has increased steadily since 2000 (FAO 2011) as a result of an increased area under production, and improved planting materials and technologies. Eight new cassava varieties and three new yam varieties, which are high yielding and disease resistant, have been developed and released by the NARS (Salifu 2011).

Nigeria enjoys the availability of well-tested, new and high-yielding cassava varieties developed by IITA and the National Root Crops Research Institute (NRCRI). To date, 49 new cassava varieties and 21 new yam varieties, which are high yielding and disease resistant, have been developed and released. Five sweet potato varieties including orange-fleshed varieties were also developed in collaboration with the International Potato Center. Uptake of the new cassava varieties by farmers was initially slow because of insufficient good quality planting materials and poor extension service (Ekwe 2012). Considering this, IITA and NRCRI, in collaboration with other relevant national stakeholders, developed a technology for rapid multiplication of cassava stem cuttings (Njoku et al. 2011). A study carried out in Akwa Ibom State, Nigeria, in 2010 indicated that about 54 per cent of cassava farmers adopted the technology (CEDP 2010) and about 33 per cent of cassava farmers are using the knowledge to multiply stems of improved cassava varieties for sale to other farmers. However, the technology transfer system needs to be scaled up.

In recent times, tissue culture, molecular biology and genetic engineering have been used to research the genetics of root and tuber crops with an emphasis on key traits of special interest to end-users (Okogbenin et al. 2011). Cassava genotypes that have high amounts of pro-vitamin A have been developed in Nigeria to help reduce vitamin A deficiency-related diseases such as night blindness, stunting, wasting and predisposition to common infections and even death (Egesi et al. 2011).

In Cameroon, cocoyam production has declined significantly since 1983 due to a root rot disease principally caused by *Pythium myriotylum*. Research was initiated in 1986 to develop tolerant/resistant cultivars with acceptable agronomic and sociological characteristics. Diseases, pests and lack of good planting materials continue to hinder the production of root and tuber crops in DRC.

While farmers have adopted modern maize and cowpea varieties, adoption of improved germplasm and practices has been slow for other crops and livestock. Despite the vibrant commercial chains for cassava marketing, farmers are not adopting the newly released varieties at the expected rates. Given the pressure on resources in the farming system, the successes with conservation agriculture (CA) in Ghana are important (further information on CA can be found in Chapter 7 on the cereal-root crop mixed farming system).

Significant progress with animal health has laid the basis for future development of livestock industries, and food processing technologies have underpinned the mechanization of cassava processing including the preparation of gari and starch.

Markets and trade

There is a long tradition of trade networks in western Africa (Haggblade et al. 2012) which link the root and tuber crop farming system to the coastal cities and ports, and to the northern crop-livestock farming systems including the cereal-root crop mixed, agropastoral and pastoral farming systems. These networks have developed markedly since the 1950s. Thus, it is no surprise that yam marketing and cassava commercialization have been successfully developed in west Africa, underpinned by experienced traders and food processors to supply the large-scale urban markets for prepared cassava-based foods (Nweke 2004). This is potentially a model for other regions of Africa. While large volumes of cassava chips were exported to Rotterdam for livestock feed, recently cassava chips have begun to be supplied to the rapidly growing, domestic animal feed industry. The supply chains for industrial purposes are established and expanding, notably for starch and bioenergy.

In Ghana, the presence of a functional, regional market for the west African sub-region at Techiman, where high-value crops such as maize and yams are in high demand, serves as an incentive to attract more farmers into root crop production. New food and food products are being developed by research to expand the market and create future, income-generating opportunities for root crops, particularly cassava. In Ghana, the Guinness brewery has developed a new brand of beer using cassava roots (Box 6.3), which has created another market for cassava farmers.

Cassava is a highly perishable crop, and in Nigeria it enters the commodity market in processed form, either as dried chips, gari, starch, flour or ethanol. About half of the Nigerian crop is marketed as pre-cooked gari (Phillips et al. 2004). However, the simplest form of processing is chipping and sun-drying the chips for use in downstream industries such as starch and animal feed. The availability of large quantities of chips allows entrepreneurs to supply new export markets such as the fast-growing, cassava-based fuel ethanol

industry in China. There are existing dried cassava chip supply chains in Nassarawa and Benue States in Nigeria, targeted to the Dawanu market in Kano; it was estimated in 2005 that about 4 per cent of all cassava in Nigeria (some four million tonnes of fresh roots or one million tonnes of chips) passed through Dawanu market on its way to Sahelian West Africa. As also illustrated by the Techiman market in Ghana, well-functioning markets are a driver for increased root and tuber crop production.

The long-term challenge for Nigerian farmers is to produce at prices and quality standards that are competitive with the world market (Nwosu and Asumugha 2003). Import substitution is being used to create new markets for cassava under the Nigerian government's Agricultural Transformation Action Plan (ATA) (Box 6.3). The goal is to add an additional 17 million tonnes of cassava to the domestic food supply. The future economic growth of the cassava sub-sector depends on how competitive Nigerian cassava is on the global market place (Knipscheer et al. 2007).

In DRC cassava contributes about 60 per cent of dietary energy intake per person (Lulombo et al. 2002). In contrast to rural areas where access to cereals is limited, cassava root consumption in urban areas (with access to maize, rice and wheat, mostly imported), has continued to fall since 1991. The level of use and trade in cassava leaves in DRC is undocumented. Cassava is sold through farm-gate sales, village markets, wholesaling and retailing in urban centres. Lack of market information, high taxes, and poor roads, transport and market infrastructure adversely affect the distribution and marketing of cassava in DRC (Lulombo et al. 2002).

In central and eastern Africa, potato production has been expanding rapidly. During the period 1998–2004, estimates indicate that over 18 million tonnes of potato was produced in the region including Burundi, Sudan, Tanzania and DRC (Berga and Nsumba 2005, cited in Tesfaye et al. 2010). Demand created by population growth and urbanization has spurred the expansion of value-added products such as potato chips (Tesfaye et al. 2010). Existence of the Common Market for Eastern and Southern Africa Community (COMESA) and East African Community (EAC) whose policies favour interregional trade in goods and services, offers great potential for regional chip trade.

Institutions and policies

In the past, national governments have focused their policies and resources mainly on cash crops for export and on cereals, and have neglected root crops (Nweke and Haggblade 2010). However in recent times, due to population growth and urbanization, many governments and researchers are reappraising the potential of root crops to help meet future food, feed and income requirements (Edem and Nkereuwem 2015). Since cassava alone supplies more food calories than any other food crop in west Africa, it is a critical element of food systems and has become a priority for food policy. In Ghana, the government identifies root crops as a possible vehicle for national economic growth and food security as they are grown mainly by smallholders for household food security and provide income for over 60 per cent of Ghanaians. The Federal Government of Nigeria (FGN) has supported the industrial development of cassava in Nigeria. The FGN also recently launched an Agricultural Transformation Action Plan (ATA), which aims to increase domestic food supply by 20 million tonnes. At the same time, it focuses on agriculture as a business, not a development program; it focuses on developing agricultural value chains that allow farmers to make money from what they produce, through greater value-addition. Cassava

Table 6.3 Summary of trends and drivers in the root and tuber crop farming system

<i>Drivers of farming system change</i>	<i>Trends</i>	<i>Implications for farming system structure and functions</i>
Population, hunger and poverty	Increased urban population; increased immigration; extension of cropped area to marginal areas; reduced fallow period	Increased demand for root crops by rapidly urbanizing population; land degradation and reduced productivity; increased loss of biodiversity; substitution of rice and maize for sorghum and millet
Natural resources and climate	Increased deforestation through improper farming activities; annual bushfires; declining rainfall pattern	Declining soil fertility and increased land degradation undermining the sustainability of the farming system and favouring some root crops including cassava – but climate change will depress cassava and yam productivity.
Energy	Recent increases in energy costs in developing countries; increased harvesting of trees for charcoal production and increased consumption of fuelwood for domestic use	Increased charcoal burning and fuelwood use leading to deforestation, erosion and declining soil fertility; lack of fuel constrains mechanization and transport to markets
Human and social capital	Root crops a major livelihood for women; inaccessibility of land to women; high illiteracy rate	Unequal access to land and credit affect women's awareness of technologies and inhibit potential increases in productivity
Science and technology	Rapid increase in area under cultivation due to availability of planting materials of high yielding varieties	Increase in production through intensification leading to possible nutrient mining and soil degradation
Trade and markets	Presence of regional markets; poor road and market infrastructures; lower producer price; unorganized market and inadequate processing facilities	Increased demand for produce; low investment in improved production practices
Institutions and policies	Root and tuber crops identified by governments as vehicle for national economic growth and food security; importation of cheap food from OECD countries due to trade liberalization; property rights and land tenure systems do not favour vulnerable groups esp. women and migrant farmers	Increased production for food security; trade liberalization and competition from imported cereals acting as disincentive for investment; limited tenure security undermines landless farmers' ability to invest in the production of cassava

is one of the major crops under this transformation agenda. The ATA aims to create 1.3 million jobs across the cassava value chains. In DRC, there is no policy on the promotion of cassava either as a food security crop or an industrial crop.

Despite efforts by some national governments to promote root crop production for national food security, trade liberalization has compelled smallholder farmers in Africa to compete against cheap imports from the Organisation for Economic Co-operation Development (OECD) countries, many of which are produced under highly subsidized conditions. Low prices are good for consumers, especially poor urban consumers. However, at the same time, they are a disincentive for producers. Although technology for the production of high quality cassava flour as substitute for wheat flour in the baking industry has been developed in most countries, only Nigeria has made it a requirement to have 10 per cent cassava in the flour used for baking bread.

Institutional factors such as property rights and land tenure affect root and tuber crop production. Limited tenure security and high land rent often undermine incentives for farmers (migrant and others) to invest in root and tuber crops with a long development/maturation period and low income returns, such as cassava.

System performance

Root and tuber crop production increased by about 27 per cent between 2000 and 2010 (Table 6.4). Market drivers have led to the greatest increase (53 per cent) in potato production while the smallest increase (20 per cent) occurred in sweet potato/yam (Table 6.4). Yield per hectare increased slightly in potato and declined by up to 26.4 per cent in sweet potato and yam during the same period. During the period 1999–2001 to 2009–2010, cassava production increased by about 27 per cent while yield per hectare increased by 9.7 per cent. In regard to the major cereals, maize and rice production increased by 29 and 53 per cent respectively, while yield increased by 21.2 and 17.2 per cent respectively. The greater increase in cereal and potato production compared with that of root crops coincides with the changing market demand discussed earlier, stemming from increasing urban population and rapid economic growth.

The increase in production of the major food crops in the farming system has been possible mainly by expansion of cultivated area and not, for the most part, by using

Table 6.4 Production and harvested area of major crops in the root and tuber crop farming system

<i>Crop</i>	<i>Production (million tonnes)</i>		<i>Harvested area (ha)</i>		<i>% increase in production</i>	<i>% increase in harvested area</i>
	<i>1999/2001</i>	<i>2009/2010</i>	<i>1999/2001</i>	<i>2009/2010</i>		
Cassava	28.84	36.62	2.80	3.24	27	16
Yam and sweet potato	11.44	13.78	0.88	1.44	20	64
Potato	0.32	0.49	0.06	0.09	53	50
Maize	3.23	4.18	2.87	3.05	29	6
Rice	1.39	2.19	0.92	1.24	58	35
Sorghum	0.34	0.34	0.35	0.41	0	17

Source: Refer to Table 2.4.

Table 6.5 Common system performance indicators: root and tuber crop farming system

Variable	Crop				
	Cassava	Yam and sweet Potato	Potato	Maize	Rice
Average yield/ha (t)	11.3	9.6	5.8	1.4	1.8
Potential yield gap (t)	27.9	29.4	34.2	9.7	10.8
Calorie production/ha (kilocalories)	9.7	8.7	3.6	4.2	4.3
Protein production/ha (kg)	50	130	100	110	80
Value of production/ha (US\$)	1171	1331	870	112	–

Source: Refer to Table 2.4.

Note: Coefficients for calculation of edible energy and protein are based on Horton (1988).

yield-enhancing fertilizer, crop management practices, or improved crop varieties. Moreover, there has been limited adoption of inorganic fertilizers. The low external input use is due to poor input-output price ratios (Dittoh et al. 2012) and difficulties with market access. While there is some scope for further expansion of cultivated area in the short term, future increases in production in the medium and long term will have to come from increased productivity on existing agricultural land, accompanied by strategies to maintain and improve soil fertility to prevent further soil degradation.

Although average yield has increased slightly for all the major crops in the farming system during the 2010s, except yam, the yield gaps generally remain very large (Table 6.5). The large yield gaps for these crops are due to use of low-yielding and disease- and pest-susceptible crop varieties, and declining soil fertility coupled with low input use (Tittonell and Giller 2013). In most areas, particularly densely populated areas, there are signs of soil fertility decline as a result of continuous cropping without restoration of soil fertility (IAC 2004), including some declining crop yields. Tree density has also declined rapidly due to destumping of trees to allow mechanized land preparation. In most areas in the sub-humid zones, a few tree species predominate, the main ones being borassus palm and dawadawa trees, which are important for food security.

Notwithstanding the deplorable yield gaps in the farming system, there are many bright spots including Nigeria and Ghana where national agricultural policies have resulted in an increase in the production of major crops, particularly cassava (IFPRI 2004). In Tanzania, diversification through production of food crops for home consumption and non-traditional crops (vegetables, vanilla) and livestock for the market has enabled some farmers to successfully move out of poverty (World Bank 2008).

Strategic priorities

Dixon et al. (2001) discussed the five major strategies used by farm households to escape from poverty (refer also to Chapter 1 this volume). Table 6.6 shows the 2015 estimates for the relative importance of the five strategies for halving poverty by 2030 in the root and tuber crop farming system. The estimates emphasize farm household perspectives and strategies, and aim to improve understanding of smallholder responsiveness to policy instruments. In Table 6.6, intensification refers to greater use of external inputs and/or use of improved varieties or breeds, improved labour productivity and better farm management

Table 6.6 Relative importance of poverty escape strategies for poor and non-poor farm households

<i>Poverty escape strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total ag pop	—	54	46	100
Intensification	2.5	3	2.5	2.5
Diversification	3	3	3.5	3
Increased farm size	2	1.5	1	1.5
Off-farm income	1.5	1.5	2.5	2
Exit from agriculture	1	1	0.5	1

Sources: See Chapter 1, ‘Farm household descriptions and strategies’ and Chapter 2, ‘Household strategies’.
 Note: For definitions of the five household strategies and extreme poverty, see Chapter 1 this volume.

to optimize production. Diversification involves any changes in the farm enterprise pattern with a view to reducing poverty, increasing farm income or reducing income variability, and often includes exploitation of new market opportunities. It may involve completely new enterprises or significant expansion of existing high value enterprise.

In the farming system, intensification as a household strategy has become more important during the period 2000 to 2015, although a little less so for the better-off farm households. The farming system has substantial potential for diversification through crop-livestock integration due to the presence of regional markets such as Techiman in Ghana and Dawanu in Nigeria – if the constraints of rural road infrastructure can be overcome. Many farm households have the opportunity to diversify into processing, for example cassava, mangoes and cashew for export. Better-off households have a greater potential to diversify than poor households. Another household strategy is expansion of the farm or herd. In the less densely populated areas, particularly for better-off households in the sub-humid subsystem, potential exists for expansion of cultivated area if soil fertility constraints can be reduced. Potential for the development of alternative livelihoods – both local off-farm employment and exit from agriculture – is relatively low because of limited economic opportunities in urban areas and underdevelopment of the industrial sector within the farming system.

If the assessments of the different strategies for the extremely poor households and the non-poor households are combined, noting that approximately half the agricultural population are extremely poor, the following (decreasing) order of importance of strategies applies for the whole population: diversification, intensification, increased farm size, increased off-farm income and exit from agriculture.

The following sub-sections outline the major strategic priorities and interventions needed to support the development of agriculture in the farming system in order to halve poverty and increase income (see also Table 6.7).

Population, hunger and poverty

High-yielding varieties and integrated soil fertility management (ISFM) strategies that arrest the rapid soil fertility decline should be used to intensify the production system and increase productivity. This will help to meet the food needs of the rapidly increasing urban population in the zone. ISFM strategies that are adapted to the local conditions should be developed, to increase productivity through judicious fertilizer application and organic matter management. Conservation agriculture involving reduced tillage and use of cover crops and mulching should also be encouraged to build up soil organic matter.

Encouraging farmers to move from subsistence production and produce towards marketing, to generate income to meet household needs and reduce poverty, is also needed. The farming system has enormous potential for livestock production due to abundant forage, and integration of livestock into the farming system can provide an additional source of income to farmers through sale of animals.

Natural resources and climate

A major priority for the farming system is the promotion of climate-smart agriculture. Slash and burn agriculture should be replaced by minimum tillage while education against bush fires should be scaled up, to increase awareness of the need to arrest soil erosion and degradation caused by exposure of the soil to the impact of rainfall. Afforestation is needed in areas where trees have been removed for charcoal production, and where vegetation cover has been removed due to improper farming practices. This will increase productivity and system resilience.

Energy

With rapid urbanization and the rising cost of energy in most parts of Africa, wood charcoal will continue to be the main source of household energy for cooking. Establishment of woodlots for firewood and charcoal production should therefore be promoted to reduce pressure on the natural forest. Government could step in by developing policies and regulations that will provide tax incentives for private individuals and companies to establish woodlots and forests specifically for the production of charcoal, using appropriate tree species with short rotation periods. In addition, stakeholders including governments, development partners, NGOs and scientists could assist in disseminating appropriate technologies for efficient processing and utilization of charcoal, such as technologies with high biomass conversion rates including improved kilns and energy-efficient stoves. Similar incentives are required to support distributed renewables and bioenergy in communities.

Institutions and policies

Land tenure reforms should be undertaken to enhance access to land by vulnerable groups such as women and landless migrant farmers. For instance, there is the need to give legal recognition to women's land rights in order to reverse discrimination against women. This could be achieved through land registration programmes that recognize women's rights. This will not only improve the security of land for women but also raise agricultural productivity and improve food security (Bezabih and Holden 2010; Deininger et al. 2011) considering that over 70 per cent of farming activities are undertaken by women. According to Byamugisha (2013), improving women's access to resources such as fertilizer and land can improve their agricultural yields by as much as 10–30 per cent.

In most countries, there are no specific policies on root and tuber crops either as food security crops or industrial crops. National governments within the root and tuber crop farming system should consider policies to support research, improve post-harvest technology development and address barriers that hinder domestic trade – often through close cooperation with the private sector. In this context, government should introduce tax incentives for entrepreneurs that utilize root and tuber crops as raw materials as was done recently by the government of Ghana for the use of cassava as local raw material for the brewery industry.

Science and technology

The bulkiness of the root crops, lack of value chains for potential diversification of products, and poor transport infrastructure in most areas of the farming system have negatively affected produce prices and household income. To expand the range of commodities and increase productivity for the farming system, including cassava, horticulture and animals, more appropriate technologies for production and processing should be developed. Measures are required to improve the quality and standardize existing products to assist marketing (Box 6.3). Improved value-addition will ensure that farmers can reduce losses, dispose of surplus produce at remunerative prices and diversify to new products. In Ghana, for example, post-harvest losses in root and tuber crops can be as high as 20–50 per cent (MoFA 2007).

While the crops best-adapted to the agroecology are cassava and yam (Figure 6.5), pest and disease pressure is very high under low input conditions. There is a substantial difference in yields between the high and low input farming, principally because of poor soil nutrient availability, high pest and disease pressure, and land workability constraints in the humid parts (van Velthuis et al. 2013). Under low input farming – as at present – cassava, yam, sweet potato (to some degree) and pasture predominate (notably, no legumes).

Figure 6.5 Rainfed suitability profiles for the root and tuber crop farming system.

Source: van Velthuisen et al. (2013).

However, as agricultural services and markets develop and moderate-to-high input farming becomes feasible, the range of adapted crops expands to include cowpea, groundnuts, maize, climbing beans (*Phaseolus* spp.), soybean and sugarcane – a mix of legumes and commercial crops.

Markets and trade

Presently, access to markets and the range of options within markets are limited. For example, the vast majority of cassava roots are processed at the village level by a variety of micro-scale methods into many different products that cater for local customs and preferences. Medium and large processing plants are forced to operate seasonally and at low capacity. Thus there is the need to build efficiency and competitiveness into the production and processing of roots and tubers, cereals, legume crops and livestock to increase incomes of small producers, including through collective action and farmer associations. The traditional market for cassava products is geared to low-income consumers. As the African economy further develops, the question is whether product quality can be improved sufficiently to make products attractive to the growing market of higher income urban consumers – without significant increases in transport and processing costs. This suggests the need to diversify into new and niche markets.

Box 6.3 Improving access to market

Improving farmers' access to market is important for food security and income generation for smallholder farmers in the root and tuber crop farming system. Farmers' access to market could be enhanced through value-addition and development of a range of products from the crops. In Nigeria and Ghana, development of cassava was accelerated by special presidential initiatives. These initiatives provided opportunities for production, processing and export of cassava products.

Under its Agricultural Transformation Action Plan, the Nigerian government has created new markets for cassava: these include high quality cassava flour to be used in replacing some of the wheat flour being imported to produce bread; high fructose cassava syrup to replace the 200,000 tonnes of sugar currently being used in the juice manufacturing industry; dried cassava chips; and the production of ethanol.

In Ghana, in order to find a solution for a 30–40 per cent surplus in cassava production, scientists developed cassava-based products as substitutes for expensive raw materials in industries ranging from pastries to plywood. These include techniques for converting fresh cassava roots into adhesives for paper and plywood, glucose syrup and industrial alcohol. Recently the brewery industries in Ghana started using cassava roots for the production of beer. Guinness Ghana Brewery Ltd produced Ghana's first beer from cassava 'Ruut extra premier' in December 2012, and in March 2013 Accra Brewery Ltd launched its cassava-based 'Eagle' brand in partnership with the Dutch Agricultural Development and Trading Company (DADTCO). DADTCO travels to smallholder farms with a mobile processing unit. The company buys directly from farmers, processes the roots on the spot and sells in bulk to the brewery. In Nigeria, the Coca-Cola Company is being encouraged to use sweeteners from local cassava.

Also, effort should be made to better link production areas to urban markets through construction and improvement of feeder roads. Improving information flow and developing synergy between the different actors in the value chain (production and marketing system) will also enhance farmers' access to market.

System conclusions

In the root and tuber crop farming system, poverty is pervasive with about half the rural and agricultural populations living on less than US\$1.25 per day – as with many other African systems. However, in contrast to some other African farming systems, this system has great agricultural potential because of its high biomass productivity combined with its suitability for commercial tree crops, cassava, horticulture and livestock, and proximity to major urban centres and export ports. In coming years, the system is expected to respond to the rapidly expanding export demand for tree crops and urban and industrial demands for root and tuber crops. Currently, the policy, economic and institutional environments are not creating adequate incentives for sustainable, increased agricultural productivity. Underinvestment in rural infrastructure including roads, storage and processing facilities generates high transaction costs and renders smallholder farmers less competitive in the export market. Gender inequality, low levels of education, poor governance and trade liberalization continue to inhibit agricultural production.

Table 6.7 Summary of strategic interventions for the root and tuber crop farming system

<i>Drivers of farming system evolution</i>	<i>Intervention</i>	<i>Implementers</i>	<i>Implications for farming system structure and function</i>
Population, hunger and poverty	Encourage intensification through use of integrated soil fertility management technologies; introduce high yielding crop varieties	NARS, NGOs, policy makers, businesses	Increased productivity to meet rapidly increasing urban population
Natural resources and climate	Promote minimum tillage in place of slash and burn agriculture; promote afforestation and education against rampant bush fires	NGOs, policy makers	Increased system resilience and productivity
Energy	Encourage establishment of woodlots for use as firewood and as raw materials for charcoal production; encourage bioenergy and renewables	NGOs, policy makers, businesses	Increased access to firewood and reduced pressure on dwindling forest
Sociocultural norms, human capital	Promote literacy among rural people; land tenure reforms to enhance female farmers' access to land; remove barriers to female access to credit and markets	Policy makers, NGOs	Increased productivity among smallholders; increased access to land and natural resources by women
Science and technology	Integrate soil fertility management strategies to arrest declining soil fertility; build capacity of research and extension to develop and extend technology to farmers	NARS, NGOs, farmer-based organizations, policy makers, donors	Increased farming system sustainability and productivity of crops; increased access to improved crop management technologies
Markets and trade	Improve access to input-output markets; investment in rural infrastructure; development of new food and non-food products	Agribusiness and private sector	Increased profit margin for farmers; value-addition to traditional staple crops; reduction in production and transaction costs; income-generating opportunities created
Institutions and policies	Improve land tenure and access rights for women and landless migrants through policy reforms; promote cassava in policies as food security and industrial crop	Policy makers, NGOs, NARS, donors	Increased access to land by landless women and migrant farmers; increased investment in root and tuber crop production; improved food security

Analysis of the system suggests that the household strategies for escaping poverty are, in decreasing order of importance: diversification, intensification, increased farm size, increased off-farm income and exit from agriculture (of course most households pursue mixed strategies). Increased productivity requires wider use of high-yielding crop varieties coupled with integrated soil fertility management to replenish declining soil fertility.

To reduce hunger, halve poverty and lay the foundation for rural economic growth, priority must be given to interventions that make small farms more productive and competitive within the existing social and cultural environment. Much could be achieved through strengthened incentives for smallholders to boost productivity, along with improved access to markets. Further gains could be made by strengthening research, extension (including ICT-based) and other agricultural support service organizations (to promote adoption of productive technologies), and by improving transport and market infrastructure (to upgrade product quality, improve access to niche markets and promote value-addition). Policy and institutional reforms should encourage private-public partnerships in value chain development and address land administration to ensure that vulnerable groups such as women, poor farmers and migrants gain productive access to agricultural resources. The land administration could be through market-based land reforms, strengthened public land administration and functional, community land tenure – framed to ensure sustainable resource management. Measures that reduce households' vulnerability to natural and economic shocks should also be implemented, including the introduction of climate-smart agriculture, insurance mechanisms, pest- and disease-tolerant crop varieties and improved crop production practices that conserve soil moisture and build soil organic matter.

References

- Adjei, O.E., Aikins, S.H.M., Boahen, P., Chand, K., Der, I., Lu, M., Mkrtumyan, V., Samaraweera, S.D. and Teklu, A. (2003) *Combining Mechanization with Conservation Agriculture in the Transitional Zone of Brong-Ahafo, Ghana*. Working Document Series 108, Ghana; www.icra-edu.org/objects/public_en/Ghana2003FS_reprt.pdf.
- Adjei-Nsiah, S., Issaka, R.N., Fenning, J.O., Mapfumo, P., Anchirina, V. and Giller, K.E. (2010) Farmers' perceptions of climate change and variability and existing opportunities for adaptation in Wenchi area of Ghana. *The International Journal of Climate Change: Impact and Responses*, vol 2, no 2, pp. 49–60.
- Adjei-Nsiah, S., Leeuwis, C., Giller, K.E., Sakyi-Dawson, O., Cobbina, J., Kuyper, T.W., Abekoe, M. and Van Der Werf, W. (2004) Land tenure and differential soil fertility management practices among native and migrant farmers in Wenchi, Ghana: Implications for interdisciplinary action research. *Njas-Wageningen Journal of Life Sciences*, vol 52, pp. 331–348.
- Adjei-Nsiah, S., Leeuwis, C., Sakyi-Dawson, O., Giller, K.E. and Kuyper, T.W. (2007) Exploring diversity among farmers for orienting interdisciplinary action research on cropping system management in Wenchi, Ghana: the significance of time horizons. *International Journal of Agricultural Sustainability*, vol 5, pp. 176–194.
- Africa Progress Panel (APP) (2015) *Power, People, Planet: Seizing Africa's Energy and Climate Opportunities – Africa Progress Report*. www.africaprogresspanel.org.
- Agwu, A.E. and Anyaeche, C.L. (2007) Adoption of improved cassava varieties in six rural communities in Anambra State, Nigeria. *African Journal of Biotechnology*, vol 6, no 2, pp. 89–98.
- Agyemang-Bonsu, W.K., Minia, Z., Dontwi, J., Dontwi, I.K., Buabeng, S.N., Baffoe-Bonnie, B. and Frimpong, E.B. (2008) *Ghana Climate Change Impacts, Vulnerability and Adaptation Assessments*. Accra: Environmental Protection Agency.
- Akinbade S.A., Hanna, R., Nguenkam, A., Njukwe, E., Fotso, A., Doumtsop, A., Ngeve, J., Tenku S.T.N. and Lava Kuma, P. (2010) First report of the Esat African cassava mosaic

- virus-Uganda (EACMV-UG) infecting cassava (*Manihot esculenta*) in Cameroon. *New Disease Reports*, vol 21, pp. 22.
- Asamoah Larbi (2012) *Sierra Leone Country Pasture/Forage Resources Profile*. www.fao.org/ag/aggp/AGPC/doc/pasture/forage.htm.
- Asumugha, G.N., Njoku, M.E., Okoye, B.C., Aniedu, O.C., Ogbonna, M.C., Anyaegbunam, H.N., Akinpelu, O.A., Ibeagi, O. and Amaefula, A. (2009) An analysis of the supply for seed yams in Nigeria. *African Journal of Business Management* vol. 3, no. 1, pp. 28–31.
- Badu Apraku, B., Fakorade, M.A.B., Ouedrago, B., Carsky, R.J. and Menkin, A. (2003) Maize revolution in west and central Africa. *Proceedings of a Regional Maize Workshop*, IITA-Cotonou, Benin, 14–18 May 2001. WECAMAN/IITA.
- Berga, L. and Nsumba, J. (2005) *PRAPACE Annual Report for the Period October, 2003 to September, 2004*. Kampala: CIP/PRAPACE.
- Bezabih, M. and Holden, S. (2010) *The Role of Land Certification in Reducing Gender Gaps in Productivity in Rural Ethiopia*. EFD Discussion Paper 10–23. Environment for Development.
- Byamugisha, F.F.K. (2013) *Securing Africa's Land for Shared Prosperity: A Programme to Scale Up Reforms and Investments*. Africa Development Forums series. World Bank.
- Cassava Enterprise Development Project (CEDP) (2010) *Impact Assessment Evaluation of Cassava Enterprise Development Project (CEDP) Implemented in Akwa Ibom, Cross River and River States, Nigeria*. Technical Report submitted to IITA Ibadan, Nigeria, May 2010.
- Deininger, K., Ali, D.A. and Alemu, T. (2011) Impacts of land certification on tenure security, investment, and land market participation: Evidence from Ethiopia. *Land Economics*, vol 87, no. 2, pp. 312–334.
- Devereux, S. (2001) Livelihood insecurity and social protection: a re-emerging issue in rural development. *Development Policy Review*, vol 19, no 4, pp. 507–509.
- Dittoh, S., Omotesho, A., Belemvire, A., Akumba, M. and Haider, K. (2012) *Improving the Effectiveness, Efficiency and Sustainability of Fertilizer Use in Sub-Saharan Africa*. Policy Research Paper 3, Global Development Network, Global Research Project, Supporting Policy Research to Inform Agricultural Policy in Sub-Saharan Africa and South Asia, New Delhi, India.
- Dixon, J.A., Gibbon, D.P. and Gulliver, A. (2001) *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World*. FAO and World Bank.
- Donatelli, M., Rosenzweig, C., Stockle, C.O. and Tubiello, F.N. (2000) Effects of climate change and elevated CO₂ on cropping systems: Model predictions at two Italian locations. *European Journal of Agronomy*, vol 13, pp. 179–189.
- Edem, I.D. and Nkereuwem, M.E. (2015) Crucial roles of tuber crops and the development activities in the global food system. *American Journal of Agricultural Science*, vol 2, no 2, pp. 42–49.
- Egesi, C., Olananni, B., Mbanaso, E.N.A., Okogbenin, E., Ekwe, K.C., Fregene, M. and Nwosu, K.I. (2011) Biofortification of cassava for enhanced food and nutrition security. In C.O. Amadi, K.C. Ekwe, G.O. Chuku, A.O. Olojede and C.N. Egesi (eds) *Root and Tuber Crops Research for Food Security and Empowerment*. Snapp Press Ltd, pp 163–176.
- Ekwe, K.C. (2012) Cassava stem multiplication technology: A viable option for industry development. *Knowledge for development*. Observatory in science, technology and innovation for ACP agricultural and rural development, CTA and S&T. www.Knowledge.cta.int/Dossiers/Commodities/Cassava/Feature-articles/Cassava-Stem-Multiplication-Technology-a-Viable-Option-for-Industry-Development.
- FAO (2011) *The State of Food and Agriculture 2010–2011*. FAO.
- FAOSTAT (undated) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- Fermont, A.M. (2006) Cassava and soil fertility in intensifying smallholder farming systems of East Africa. PhD Thesis, Wageningen University.
- Hagblade, S. et al. (2012) Cassava commercialization in Southeastern Africa. *The Journal of Agribusiness in Developing and Emerging Economies*, vol 2, no 1, pp. 4–40.
- Hilderink, H. et al. (2012) *Food Security in Sub-Saharan Africa: An Exploratory Study*. PBL Netherlands Environmental Assessment Agency.

- Horton, D. (1988) *Underground Crops: Long-Term Trends in Production of Roots and Tubers*. Winrock International.
- IAC (InterAcademy Council) (2004) *Realising the Promise and Potential of African Agriculture*. Inter Academy Council, Amsterdam.
- IFPRI (International Food Policy Research Institute) (2004) *Annual Report (2003–2004)*. IFPRI, Washington DC.
- IITA (International Institute of Tropical Agriculture) (2012) *Yam*. www.IITA.org/yam.
- Islam, M.J., Haque, M.Z., Majunde, U.K. and Hossain, M.F. (2000) Growth and yield potential of nine genotypes of sweet potato. *Pakistan Journal of Biological Sciences*, vol 5, pp. 537–538.
- Jones, J.H.M. and Sakyi-Dawson, O. (2001) Linking formal and informal financial intermediaries in Ghana: A way to increase women's access to financial services? In B. Lemire, R. Pearson and G. Campbell (eds) *Women and Credit, Researching the Past, Refiguring the Future*. Oxford University Press.
- Kamau, J., Melis, R., Laing, M., Derera, J., Shanahan, P., Eliud, C. and Ngugi, K. (2011) Farmers' participatory selection for early bulking cassava genotypes in semi-arid Eastern Kenya. *Journal of Plant Breeding and Crop Science*, vol 3, no. 3, pp. 44–52.
- Knipscheer, H., Ezedinma, C., Kormawa, P., Asumugha, G., Makinde, K., Okechukwu, R. and Dixon, A. (2007) *Opportunities in the Industrial Cassava Market in Nigeria*. UNIDO/International Institute of Tropical Agriculture (IITA).
- Langeveld, H., Quist-Wessel, F. and Dixon, J.M. (2015) *An Alternative Approach for Assessing Indirect Land Use Change (ILUC) Effects: Linking Biomass Availability, Land Cover and Cropping Intensity*. Poster, IEA Bioenergy Conference, 27–29 October 2015, Berlin, Germany.
- Lulombo, S., Bidiaka, M., Tata, H., Koko, N., Lutete, D., Khonde, M. and Makoko, E.N. (2002) Cassava sub-sector analysis in Democratic Republic of Congo. In J.M. Mbwika, P. Ntawuruhunga, C. Kariuki and A. Makhoka (eds) *Proceedings of the Regional Workshop on Improving the Cassava Sub-Sector*. ICRAF, Nairobi, Kenya, 8–12 April 2002, pp 26–34.
- MoFA (2007) *Food and Agriculture Sector Development Policy (FASDEP II)*. Ministry of Food and Agriculture, Accra, Ghana.
- NAELS (2009) *National Agricultural Extension Liaison Services Annual Performance Evaluation, 2009 Wet Season Report*. NAELS.
- Njoku, D., Egesi, C.N., Offei, S.K., Asante, I., Vernon, G., Okogbenin, E., Ekwe, K.C., Ezulike, T.O., Eke-Okoro, O.N. and Nwosu, K.I. (2011) Prospects for biofortification of farmers' preferred cassava varieties in Nigeria. In C.O. Amadi, K.C. Ekwe, G.O. Chuku, A.O. Olojede and C.N. Egesi (eds) *Root and Tuber Crops Research for Food Security and Empowerment*. Snapp Press Ltd, pp. 163–176.
- Nweke, F.I. (2004) *Processing Potential for Cassava Production Growth in Sub Saharan Africa*. COSAC working paper No.II, collaborative study of cassava in Africa, IITA.
- Nweke, F. and Haggblade, S. (2010) The cassava transformation in west and central southern Africa. In S. Haggblade and P.B.R. Hazell (eds) *Successes in African Agriculture: Lessons for the Future*. Johns Hopkins University Press.
- Nweke, F.I., Spencer, D.S.C and Lynam, J.K. (2002) *The Cassava Transformation: Africa's Best-Kept Secret*. Michigan State University Press.
- Nwosu, K.I. and Asumugha, G.N. (2003) Export potentials for Nigerian cassava and cassava products in the international market. *Paper Presented at a Workshop on Nigerian Export Promotion, Nigerian Export Promotion Council, Enugu Zone, Niger Heritage Hotel, Onitsha, Nigeria, 11 September 2003*.
- Ofuoku, A.U. and Isife, B.I. (2009) Causes, effects and resolution of farmers–nomadic cattle herders conflict in Delta State, Nigeria. *International Journal of Sociological Anthropology*, vol 1, no 2, pp. 47–54.
- Okogbenin, E., Egesi, C.N. and Fregene, M. (2011) Marker assisted breeding in cassava. In C.O. Amadi, K.C. Ekwe, G.O. Chuku, A.O. Olojede and C.N. Egesi (eds) *Root and Tuber Crops Research for Food Security and Empowerment*. Snapp Press Ltd, pp. 125–144.
- O'Sullivan, J.N. (2010) *Yam Nutrition, Nutrient Disorders and Soil Fertility Management*. ACIAR Monograph No. 144. Australian Centre for International Agricultural Research.

- Phillips, J.P., Taylor, D.S., Sanni, L and Akorada, M.O. (2004) *A Cassava Industrial Revolution in Nigeria: The Potential for a New Industrial Crop*. International Fund For Agricultural Development and Food and Agricultural Organization.
- PNDRT (Programme National de Developpement des Racines et Tubercules) (2005) *Rapport des etudes de base dans les cinq antennes*. Electronic file. Ministry of Agriculture and Rural Development.
- Saïdou, A., Adjei-Nsiah, S., Kossou, D., Sakyi-Dawson, O. and Kuyper, T.W. (2007) Sécurité foncière et gestion de la fertilité des sols: études de cas au Ghana et au Bénin. *Cahiers Agricultures*, vol 16, no 5, pp. 1–8.
- Saïdou, A., Kuyper, T.W., Kossou, D., Tossou, R. and Richards, P. (2004) Sustainable soil fertility management in Benin: learning from farmers. *NJAS-Wageningen Journal of Life Sciences*, vol 52, pp. 349–369.
- Salifu, A.B. (2011) Contribution of research to the development of root and tuber crops industry in Ghana. *A Paper Presented during West African Agricultural Productivity Program-West Africa Root and Tuber Crops Conference*, Accra, 12–14 September 2011.
- Soro, D., Dao, D., Girardin, O., Bi, T.T. and Tschannen, B.T. (2010) Adoption d'innovations en agriculture en Cote d' Ivoire: cas de nouvelles varieties d'igname. *Cahiers Agricultures*, vol 9, no 6, pp. 403–410.
- Tesfaye, A., Lemaga, B., Mwakasendo, J.A., Nzohabonayoz, Z., Mutware, J., Wanda, K.Y., Kinyae, P.M., Ortiz, G., Crissman, C. and Thiele, G. (2010) *Markets for Fresh and Frozen Potato Chips in the ASARECA Region and the Potential for Regional Trade: Ethiopia, Tanzania, Rwanda, Kenya, Burundi and Uganda*. International Potato Center (CIP), Lima, Peru. Working Paper 2010–1.
- Tittonell, P. and Giller, K.E. (2013) When yield gaps become poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*, vol 143, pp. 76–90.
- Vanlauwe, B., Mutuo, P., Mahungu, N. and Pypers, P. (2013) Boosting the productivity of cassava-based systems in DR Congo. *Best Practice*, 8, IITA.
- van Velthuizen, H., Fischer, G. and Hizsnyik, E. (2013) *Technical Annex: FS Characterization with GAEZ Data. The African Farming Systems Update Project: Farming Systems and Food Security in Africa – Priorities for Science and Policy under Global Change*. IIASA.
- World Bank (2008) *World Development Report: Agricultural for Development*. World Bank.
- World Bank (2011) *World Development Report 2012: Gender Equality and Development*. World Bank.

7 The cereal-root crop mixed farming system

A potential bread basket transitioning to sustainable intensification

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Key messages

- The cereal-root crop mixed farming system is a potential food basket of west and central Africa, with an area of more than 200 million ha, good rainfall and an agricultural population of only 43 million.
- This crop-livestock system features a variety of cereals, legumes, cattle and small ruminants and has similarities to the maize mixed farming system in east and southern Africa.
- The main drivers of change are population increases and, recently, improving market access for grain and livestock.
- The long-term prospects for agricultural growth and sustainable intensification are excellent. There are great potential knowledge-intensive innovations such as mechanized conservation agriculture.
- Key enabling factors are transport infrastructure, enabling policies and farmer organizations to underpin market access and farmer-to-farmer learning and innovation.

Summary

The cereal-root crop mixed farming system has the most suitable climate in Africa for tropical cereals such as maize, sorghum and millet. Cereals and legumes are grown throughout the zone, usually intercropped, including with roots and tubers, vegetables and other crops. Cotton is more common in the north and root crops in the south.

Many farmers in the farming system use hand cultivation under rainfed conditions, with limited use of fertilizer. Animal traction is limited to areas where there has been successful commercialization of crops such as cotton and higher yielding maize composites. Tractor disc ploughing is increasing and is a concern for generally fragile soils. There is a lower population density compared with other farming systems in similar agroecologies, and medium farm sizes. However, rapidly increasing population densities are resulting in smaller farm sizes, increasing inequalities in land distribution and a widespread decline in soil health. As a result, traditional techniques of maintaining soil fertility are no longer sufficient to sustain food production. Moreover, there are continuing conflicts between

settled crop cultivators and nomadic Fulani cattle herders, though many Fulani have settled, managing mixed crop livestock systems. Despite the suitable agroecological conditions, 55 per cent of the population subsists on less than US\$1.99 per day. While overall the farming system has been able to meet food requirements, a significant proportion of the population is undernourished and experiences food shortages during the hungry period (end of the dry season and beginning of the wet season). Migration to urban centres and for seasonal work in the forest-based farming system helps provide household remittances but is limited by job opportunities.

The farming system has undergone three key changes – increased area available for agriculture due to release of land from serious human and cattle disease, increased importance of some crops (maize, rice, soybean) and intensification of farming. Markets have emerged for the use of cereals (mostly maize) and cassava crops for commercial-scale production of livestock feed, starch and ethanol; soybean for feed stocks and vegetable oil; sorghum for beer; and vegetable crops for urban markets. Root and tuber crops, especially yams, remain mainstays. Increasing demand for food associated with rapid population increase, urbanization and changes in diet, offers opportunities for value-adding agricultural products, such as high value horticulture products, including potatoes, under irrigation in the cool dry season.

With its favourable climate and capacity to produce surpluses, the cereal-root crop mixed farming system has, for some time, been considered the future bread basket of Africa and has, historically, also been an important source of export earnings. While food production has previously been met through area expansion, the scope for further expansion is now limited. Intensification is the most feasible pathway out of poverty and to meet increased demand for food and improved livelihoods. Improved varieties, capacity building and more integrated sustainable farming techniques such as conservation agriculture (CA), agroforestry, integrated pest management (IPM) and integrated crop/livestock intensification are required to both improve soil conditions and meet the increasing demand for agricultural produce. Most of these innovations are knowledge and management intensive, and increased adoption will require investment in enabling environments and farmer learning.

Unlike in eastern and southern Africa where the system has changed to the maize mixed farming system, the development pathways for the current areas of cereal-root crop mixed farming system are likely to be different – involving increased mechanization (especially in west Africa), diversification including trees for wood and fuel, legumes, livestock intensification, and increased medium-scale agriculture in response to emerging markets and favourable agroecology. There are opportunities for agribusiness and private investment in seed inputs, purchasing, grain drying and storage facilities and feed mills, among others. Over time, the proportion of root crops may decline somewhat, unless use of cassava in livestock rations increases.

Well-targeted institutional support, along with public and private investment, is required to improve education, human capacity, transport and road infrastructure, regional employment opportunities, and provide credit, build the agribusiness skills of women, develop more efficient markets within and between farming systems and countries, and continue to manage tsetse, sleeping sickness, animal trypanosomiasis and river blindness (*Onchocerciasis*) diseases. Promising cross-country initiatives such as Agriculture Growth Corridors as part of the public-private-sector partnership Grow Africa must be accompanied by national and local policies supportive of agriculture in the farming system, and equip households to adapt farming and livelihoods to drought, climate change and changing markets.

Governments must also play a greater role in mitigating agricultural land degradation and rehabilitating degraded landscapes in coming decades as greater pressures are put on the natural resource base. Trained service providers who conduct contract zero-tillage planting and appropriate herbicide application as part of integrated weed management strategies, and greater adoption of CA, will assist this. Research on locally specific adaptations of CA, and breeding and supply of locally suited soybean varieties, root, tuber, tree and vegetable crops is needed.

Overall description of the farming system and subsystems

Basic description and importance

The cereal-root crop mixed farming system (Figure 7.1) extends in a band across central Africa from Senegal and Guinea through northern Côte d'Ivoire to Ghana, Togo, Benin, Nigeria, northern Cameroon, the southern part of Chad, across the northern part of Central African Republic and southern Sudan.

The farming system has a warm tropical climate, an annual rainfall of 800 to 1200 mm, and a length of growing period ranging from 150 to 240 days. There is considerable excess of rainfall over evapotranspiration during the growing period so that the risk of severe drought is relatively low. However, devastating droughts have occurred in the past in the dry sub-humid parts of the zone, such as in 1930, 1972 and more recently.

The farming system is located between the agropastoral farming system to the north with rainfall less than 800 mm, and the root crop farming system to the south with more than 1200 mm rainfall. In Dixon et al. (2001), the cereal-root crop mixed farming system occurred in parts of southern, central and eastern Africa. However, as farmers increased the area of maize in the system during the period 2000–2015, in some areas the cereal-root crop mixed farming system has evolved into the maize mixed farming system while still retaining some small pockets with cassava, sweet potato, sorghum and millet (Chapter 3 this volume; IAC 2004).

Figure 7.1 Map of the cereal-root crop mixed farming system and subsystems.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

The cereal-root crop mixed farming system shares a number of system characteristics with the maize mixed farming system in eastern and southern Africa, particularly in the lowlands, but the cereal-root crop mixed farming system has a relatively lower population density, more unused cultivable land, higher livestock numbers per household and poorer transport and communication infrastructure. It also has higher temperatures and in some areas the presence of a tsetse challenge which limits livestock numbers and prevents the use of animal traction, particularly in the moist sub-humid zone (Dixon et al. 2001; FAO 2008). However, tsetse pressures are slowly diminishing as their habitat is increasingly disturbed by human activities.

In 2015 the total population of the cereal-root mixed farming system was 84.8 million, representing rapid annual growth since 2000, and estimated to grow to about 168 million by 2040. Approximately 50 per cent of the population were involved in agriculture (Table 7.1). Total cultivated area was 33.6 million ha, of which cereals (sorghum, millet, maize and rice) constituted two-thirds of the total, while root and tuber crops (cassava, sweet potato, yam) amounted to nearly 3 million ha, with annual leguminous crops or pulses (mostly cowpeas with some pigeon peas, dry beans) and oilseed crops (groundnut, soybean, sesame) comprising over 1 million ha and about 2 million ha respectively. Cotton accounted for nearly 1 million ha. Overall, there are about 0.14 total livestock units (TLU) per hectare and 3.7 TLU per household. These animal populations have increased over time.

In most of the countries, the farming system is regarded as the ‘grain’ belt and is often referred to as the ‘bread basket’. This is because the system has high agroecological potential for crop and livestock production, with the best moisture, solar radiation and thermal regime for tropical cereals such as maize, sorghum and millet. Soybean can be rotated with nearly all cereals in the farming system although with more difficulty in the areas with higher rainfall (unless sown to mature at the end of the rainy season). Future adoption of no-till CA systems will result in further increases of soybean in the 1000 to 1200 mm rainfall zones.

Table 7.1 Basic system data (2015): cereal-root crop mixed farming system

<i>Item</i>	<i>Data</i>
Total human population (million)	85
Agricultural population (million)	43
Total system area (million ha)	202
Cultivated area (million ha; % of total area)	33.6; 17
Irrigated area (million ha; % of cultivated area)	0.27; 1
Total livestock population (million TLU)	29
Major agroecological zone	Tropical warm subhumid
Length of growing period (average, days; core range, days)	187; 150–210
Access to services	Medium-high
Distance to 50k market (average, hr; core range, hr)	7.3; 2–10
Agricultural population density (persons/total area; persons/cultivated area)	0.2; 1.3
Livestock density (TLU/total area; TLU/cultivated area)	0.14; 0.9
Standard farm/herd size (cultivated area/household, TLU/household)	4.3 / 3.7
Extreme poverty (% of rural population)	55

Source: Refer to Table 2.4.

Staple cereals such as sorghum, millet, maize and upland rice, along with pulses (cow-peas and beans), oilseeds (groundnut and soybean), and root and tuber crops (cassava, yam and sweet potato), are widespread in the drier parts of this farming system. Although cereals and legumes, usually intercropped, are grown throughout the zone, cotton is more common in the north and root crops in the south. Crops are mainly grown under seasonal rainfed conditions in the uplands although some year-round cropping is found on the limited areas of lowland.

Farming system structure

Farming households traditionally only have usufruct rights to land (rights to use the land but no ownership or land title) under customary ownership or ‘Maliki’ law. The average farm is estimated to be 4.3 ha.

The average amount of land possessed by farming families is generally inversely related to population density. In areas of low population pressure, the amount of land farmed is in general a function of family size (labour force) and the quality of the land. As population density increases, the following changes take place: (i) farm size decreases with associated challenges with maintaining soil fertility; (ii) inequalities of land distribution often become an increasing problem; and (iii) as a result of smaller and increasingly fragmented farms, challenges with mechanization become greater. Considerable inequalities can arise in land distribution, which is often influenced by tribal leaders.

Inland valleys are natural drainage channels in the landscape, and they have a high agroecological potential because water is available or can be made available year round. Households often have two types of land, the upland fields known as *gona* or *gone* in Hausa and the hydromorphic land¹ in the lowland inland valleys known as *fadama* in Hausa. As these two land types are often not adjoining, a household farm can have several separated fields of different quality, size and position in the landscape. Households manage this combination of land in the rainy and dry seasons, to produce a mixture of crops, livestock including fish, trees, as well as engaging in off-farm activities in order to satisfy household needs and fulfil cultural obligations.

In the *fadama*, wetland or flooded rainfed rice is a dominant crop along with yams, cassava and sugarcane, with banana away from the wetlands and bordering the nearby sloping and upland fields. Irrigated vegetable crops, including sweet potato and cassava leaf production, are common in the dry season in the inland valleys.

Households generally use hand tools to cultivate three to nine ha. The amount of land that can be weeded adequately by households during the seasonal weeding bottleneck period is an important determinant of the area cultivated. Modest use of herbicides in some cases is enabling farm families to expand cropping areas. Contract application of herbicide is increasing in Nigeria and Ghana, especially for weed control in cassava-based systems (F. Ekeleme of NRCC, pers. comm., 2014). Animal traction is often found in areas where there has been successful commercialization of a crop.

Intercropping is common and popular because of its advantages over sole cropping, which include yield stability and security and higher profitability due to higher combined returns per unit area of land (Box 7.1). Growing cassava with short-duration legumes supplies both carbohydrates and protein, which provides the foundation of a healthy diet for the farming household (Howeler et al. 2013). The mix of crops varies between regions (and households), as does the relative proportion of crops used for home consumption, livestock feed and sale.

Box 7.1 Intercropping and plant phenology

Intercropping is a cropping practice that involves growing two or more crops together. The most common goal is to produce a greater yield on a unit area of land than would be obtained by a single crop. The practice takes advantage of different plant phenology and growth rates so that crops mature at different times and competition between crops is minimized. Examples are growing deep- and shallow-rooted plants, slow- and fast-growing plants, or sun-loving and shade-tolerant plants together. Careful planning is required to consider the soil, climate, crops and varieties, in particular crop competition for physical space, nutrients, water or sunlight. The practice has many benefits – it protects the soil from the direct impact of rain, reduces soil erosion from runoff and limits weed growth during the early stages of plant development. Intercropping also produces crops that can be harvested at different times during the year, increases total net income per unit area of land and reduces the risk of total crop failure. It can bring more efficient utilization of time, space and resources (water, atmospheric nitrogen and labour), greater resilience and allow a more even distribution of farm labour than sole cropping. Intercropping of compatible plants also encourages biodiversity (Altieri and Nicholls 2004) and increases the barriers to pest dispersal. The practice is a way to increase African, and world, food supplies.

The cereal-root crop mixed farming system combines millet, sorghum and cowpea in a closely coordinated system to make fuller use of the environmental resources and produce yields of starch and protein with a land equivalent ratio (LER) of more than one. Normally, day-neutral pearl millet (*Pennisetum* or *gero*) is sown first, as it matures early and helps break the hunger period. The main crops, sown when the rains are thought to be established, are cultivars of sorghum and increasingly maize, which are generally sown between the rows already planted with millet. Green maize is increasingly an important hunger breaker. Maize fits into this cropping system because it can be harvested after millet, as the rains are ending, and well before the sorghum is ready.

After weeding, and generally after harvesting the early millet, farmers usually sow a long-season, spreading, short-day photoperiodic type of cowpea. The early millet is generally harvested before the sorghum has initiated its panicle, and often the millet crop has little or no detrimental effect on the sorghum yield, which is produced much later, after the rains have ended.

Where cotton is grown, it constitutes a major source of cash and competes for labour for planting because farmers give priority to planting food crops first before sowing cotton. Consequently, cotton is often sown late, in July rather than in June.

Traditionally little mineral fertilizer is used. However, increasing numbers of households are applying small doses of fertilizer to the maize crop, especially in Nigeria and Ghana, and selling surplus production. The main sources of cash are cotton (in drier sub-zones), maize, cowpeas and vegetables. Increasingly, soybeans are found in the cropping system as a cash crop, in addition to some cassava and yam.

The household is largely food self-sufficient and sometimes has a small surplus to sell. However, poor households experience two to three months of food insecurity towards the end of the dry season and the early part of the rainy season (the so-called ‘hungry

season or gap' or *soudure* in French). During the hungry season some farmers work for food on other farmers' fields, although such work can delay planting and lowers potential productivity on their own fields. Further, many male household members, particularly of poorer households, migrate south to the forest-based farming system (Chapter 12 this volume) for casual work on plantations.

The main nutritional shortage in the 'hungry gap' period is protein, which in the dry subzone (north) is supplied mainly with millet, sorghum and maize grain which contain 8–14 per cent protein. Cowpea and groundnuts are important but lesser sources of protein due to their higher prices. To break the hungry gap in the wetter regions, maize for green-cobs and cultivars of early-flowering, day-length neutral, cowpeas are grown.

Roots and tubers remain mainstays and are an important source of nutrition and food security in the traditional mixed farming system. For example, Nigeria produces about 100 Mt/year of cassava and yam in this zone and Ghana produces over 20 Mt. Production of sweet potato (*Ipomoea batatas*) in Nigeria alone was about 3.5 Mt in 2013.

Beta-carotene-rich sweet potato varieties can provide a year-round, sustainable source of vitamin A in the diet in areas where children under five years old have significant levels of vitamin A deficiency. Yam tubers (*Dioscorea* species) tend to be higher in protein and minerals such as phosphorus and potassium than sweet potato roots, though the latter are richer in vitamins A and C. Unlike cassava, sweet potato and aroids (*Colocasia* species), the yam tubers can be stored for up to four to six months at ambient temperatures. This characteristic contributes to sustaining the food supply, especially in the food scarce period at the start of the wet season. At the farm level, cassava is stored by leaving it unharvested in the ground. Many important cultural values are attached to yam, especially during weddings and other social and religious ceremonies. In many farming communities in Nigeria and other west African countries, the size of yam enterprise is a reflection of one's social status.

Throughout the farming system, households combine crop and livestock production. Livestock are an asset for high value income generation and risk management, in addition to their traditional role in providing manure for fertilizer. While not all farmers own cattle, nearly all farm households own a few chickens and goats.

The traditional approach involves free communal grazing after harvest, with herders from the agropastoral farming system moving through the cereal-root crop mixed farming system to graze on natural vegetation and crop residues, before selling animals in local markets and in urban markets in the more humid areas to the south. Both cattle and small ruminants are important. The crop-producing sedentary Hausa (and sometimes Fulani) farmers benefit from livestock manure in the crops, while herdsman rely on crop residues for livestock feed during the dry season. In some cases herdsman drive, fatten and sell in the urban centres in the south, animals that would not thrive during the long dry season. Crop residues are also frequently important for fattening of confined animals, including those raised for religious celebrations, such as goats for export to north Africa and the Middle East.

In recent years, there has been continued conflict between crop producers and livestock herders (Fulani) along some corridors. This has encouraged the settlement of some of the herders in areas where the tsetse fly is less of a problem. Such Fulani farmers are engaging in both crop and livestock production (Figure 7.2).

A recent trend among smallholders is to divide the herd at the end of the rainy season, keeping pregnant animals and important bulls and sending the less important animals south with the Fulani herdsman. These animals are then returned to the farmer at the beginning of the next rainy season. Even more recently, the herd holder stays with the animals in the

Figure 7.2 Fulani herder settled in southwest Burkina Faso. In addition to livestock production this farmer has adopted maize and cotton farming for income diversification.

Source: Eric Kueneman.

south (since the tsetse fly is now less problematic due to tree clearing and possibly climate change) where they are often sold, with the proceeds being remitted back to the animal owners. The process allows the owners to have larger herds and to be less restricted by the lack of dry season feed (J.E. Koneke, pers. comm., ILRI-Ibadan, Nigeria 2012).

Legumes are used for household consumption with some kept for seed and sale. Soybean is becoming the most important legume sold. Legume haulms² are used primarily for livestock feed, and less often for compost or green manure. They are used for domestic animals and are sold for cash. In southern Kaduna State, Nigeria, where livestock densities are lower, the sale of residues is more common, mainly to traders from the north where peri-urban livestock keeping is increasing (Franke and de Wolf 2011).

The milk industry has historically been marginal, in part because of imported dehydrated milk (mostly from Europe). Traditional herders produce local cheeses, mostly for family use and sale in informal markets.

Crop and livestock changes and intensification

The farming system has undergone three key changes – increased area available for agriculture due to release of land from disease, increased importance of some crops (maize, soybean, rice) and intensification of farming and shortened fallows, if any (Figure 7.3).

Figure 7.3 A soybean and maize plot in southwestern Burkina Faso under no-till management with a live fence introduced to control grazing of crop residues (fence seen on right side). Photograph taken during a farmer group appraisal.

Source: Eric Kueneman.

Historically, the development of the farming systems was constrained by two major diseases, one affecting humans (*Onchocerciasis*) and one affecting animals (*Trypanosomiasis*). *Onchocerciasis* (river blindness) control efforts, especially in the 1980s, coupled with tsetse fly habitat disruption, have freed an estimated 25 million ha of cultivable land for agricultural intensification (World Bank 2009). The poultry and dairy sub-sectors in Nigeria and Ghana, as examples, have both nearly doubled since the early 2000s resulting in a growing feed demand and contributing to intensifying agriculture in the cereal-root crop mixed farming system.

There have also been substantial changes in the relative area of crops grown in some parts of the farming system over the last few decades. The shares of maize and soybean are expanding (World Bank 2009), as are small plantations of economically remunerative trees, such as smallholder teak, where land tenure is relatively secure. There are several examples in the farming system of successful development of niche products such sorghum for beer, and organic mangoes.

Maize, soybean and rice expansion

Maize has expanded north and has been promoted primarily as a sole crop to be sown with animal traction and fertilizer added. The substantial increase in maize farming over many decades reflects its much higher yield potential, changing consumer habits and

preferences (Norman et al. 1975; World Bank 2009) and its heavy promotion as the main staple cereal for the local population during the colonial period and during periods of humanitarian crises arising from natural disasters and political instability. Especially in the dry sub-humid parts, maize expanded as a result of the diffusion of improved early-maturing, fertilizer-responsive varieties, facilitated by fertilizer subsidies and production credit. Maize has been replacing sorghum for both food and feed.

The area of soybean has been expanding in countries where national economies are growing and diversifying, such as in Nigeria and Ghana, and where there is growing demand for locally formulated livestock feed and livestock products. Family farmers often intercrop soybean rows by replacing occasional maize rows with soybean. In some countries, governments promoted local soybean production by guaranteed prices until grain companies began sourcing locally rather than importing their supply.

Rice is an important crop in Africa and production, particularly of wetland rice in inland valleys, is expected to expand in the coming decades to meet the growing demand. Rice production in Nigeria rose from about 3 Mt to about 5 Mt from 2000 to 2012 (FAOSTAT), due largely to good support policies. As for maize, the economics of production depend in part on the costs of nitrogen fertilizer. Regional and national policies on fertilizer subsidies have, and will have in the future, major implications for production and productivity of these crops.

In many parts of the farming system in the south there are adequate growing days for two crops (cereals and legumes) per rainy season. However, energy costs for grain drying and storage of the first crop are currently a limiting factor, and without a strategy to dry grain or move it quickly to drier areas for sun drying, the potential for two crops per rainy season goes largely unrealized.

Cotton expansion

Cotton production is an important export-earning resource in many countries. In Burkina Faso, the largest seed cotton producer in Africa, the sector provides livelihoods to 350,000 cotton farmers and over 3 million people, with flow-on effects on trade, banking, the processing industry and transport – generally stimulating internal growth and generating tax revenue.

Some cotton farmers, particularly in the Francophone areas, are part of schemes operated by cotton companies, either fully private or partly public (i.e. parastatal). They follow a recommended package of practices with seed, fertilizer and pesticides made available to them by the companies to achieve satisfactory yields.

A multi-country, decade-long project in Francophone west Africa, implemented by FAO, is demonstrating important savings are possible through reduced use of pesticides in cotton. The project teaches IPM using farmer discovery processes and the Farmer Field School approach. This project and new Brazilian support to the same four major cotton countries in Francophone west Africa could make cotton increasingly attractive.

Groundnut

Groundnut production once flourished in the farming system in Nigeria and was a major export to Europe, but this collapsed in the late 1960s after the discovery of oil. Efforts to revive its production for export have been largely unsuccessful partly because of aflatoxin contamination of the grain. Aflatoxin is a powerful carcinogen. New approaches

(Aflasafe™) to controlling grain infection by *Aspergillus* (that produces the toxin) look promising and may help revive export markets. However, poor soil health linked to infestation by the parasitic weed *Alectra vogelli* results in poor groundnut productivity. If the aflatoxin issue is solved, export opportunities might justify the investments to overcome *Alectra* and other pests.

Livestock

Commercialization and intensification are changing the ways livestock are integrated into the farming system. Animal traction is being adopted, though sporadically, as a result of commercialized crop production (e.g. cotton and high yielding maize).

The integration of crop and livestock production is particularly apparent in intensively farmed and densely populated areas (Kamara et al. 2012). In recent years, where households have land in the inland valleys with a good year-round water supply and a source of fodder, dairy production has become an important commercial activity due to a higher and more reliable return on investment.

Recently, market integration has meant locally produced crop ingredients are used in livestock feed formulations (e.g. maize, soybean, cotton seed cake produced after cotton ginning) for intensive poultry and stall-fed livestock production including dairy (Fernández-Rivera et al. 2004; Thornton et al. 2002). Both the roots and leaves of root crops can be used as on-farm animal feed or as an ingredient in commercial animal feed. For example, before being fed to animals, cassava is chopped and spread out on a floor to wilt and is sun-dried to 12 to 14 per cent moisture content to release most of the cyanide content, making root chips and leaf pieces safe as feed for pigs, cattle, small ruminants and chickens (Howeler et al. 2013).

Farming subsystems

Two subsystems have been identified:

- (1) The *cereal-pulse root crop subsystem* (subsystem 1) is located in the drier zone in the north, typically with 140–200 days length of growing period. The rainfall is reasonably reliable and functionally monomodal with one peak in August, making it suitable for intensive arable production. Sorghum, maize and millet are the dominant cereals, grown with or without cotton. Oilseeds such as soybean, sesame and groundnut, and pulses such as cowpea are frequently companion intercrops or in rotation with sorghum, millet and maize. In more favourable areas, root and tuber crops are grown, especially cassava and sweet potato in the uplands, and cassava and yam along the inland valleys where soil moisture is available beyond the rainy season. In this farming subsystem, important cash crops are cotton, millet, sorghum, maize, cowpea and groundnut. Cotton has been an important cash crop in the subsystem for centuries.
- (2) The *root crop-cereal subsystem* (subsystem 2) is located in the moist sub-humid zone in the south, generally with 200–240 days length of growing period. There are two rainfall peaks in June and September separated by a relatively dry period in August, often referred to as the ‘little dry season’. The two growing seasons of unequal duration and this functionally bimodal rainfall regime make it more complicated for the drying of cereal and legume grains from crops sown at the onset of the first rains. One apparent trend associated with climate change is the reduction (near disappearance) of the short dry season in parts of the farming system.

Root and tuber crops such as cassava, sweet potato and yams are the most important staple crops. Cassava and yams are short-term perennials, while some cassava is left in the soil as a food reserve and a source of planting stakes. The roots and tubers are grown with maize and upland rice as well as pulses such as cowpea and oilseeds such as soybean and groundnut. These grain legumes are currently less significant, but in the future will increasingly become critical for income, soil health, pest management and human nutrition. Grain drying and storage facilities for food and oilseed legumes are generally inadequate in this humid zone.

Where the rainfall is functionally monomodal, soybean is becoming an important cash crop along with food crops such as maize, rice, cassava, yam and sugarcane, which is grown in lowland soils near rivers or other water sources.

Household demographics, assets and occupation

Table 7.2 summarizes farming system features at the household level by comparing Mali, Ghana and Nigeria. It shows an average household size of 7 to 22 with the household head 46–52 years old. The traditional extended family unit consists of more than one married man plus dependants, with most rural households in the farming system headed by males (e.g. 99 per cent in Kano and Katsina states, Nigeria). However, in Borno State, Nigeria, some 14.5 per cent of the households are headed by females (Amaza et al. 2009).

Almost all household heads are married, indicating the importance of family labour in this farming system. Traditionally, male household heads are responsible for most farm-level decision making (e.g. Nigeria, Ghana, Sikasso region; Fofana et al. 2011). Other household members are responsible for making farming decisions on specific fields. However, complex family units are increasingly breaking into simpler family units (one married man plus dependants) contributing in many areas to smaller farms, increased fragmentation of fields, younger, relatively inexperienced family heads and more diverse and decentralized decision making.

The occupational pattern is diverse and varies between regions and households. Sources of off-farm income include trading, operating a small business, handicraft, sale of charcoal and firewood, and remittances from urban employment.

Education levels are generally low. In Nigeria, 80 per cent of household members over 35 years of age have no background in formal education, whereas 40 per cent of the members between 17–35 years have some education with over 20 per cent reaching secondary level. In the Sikasso region of Mali, the household illiteracy rate is 59 per cent on average (Bamire et al. 2010). Males are generally better educated than women.

Farmer-based organizations are an important source of non-formal education and information about the type and availability of inputs and markets, group formation, farm planning and budgeting, sound agricultural practices, post-harvest management and marketing strategies. In southern Kaduna State, 50 to 65 per cent of the households belong to farmer associations such as cooperatives.

Traditionally, capital assets owned by farming families, apart from livestock, consisted largely of self-made goods, such as farm implements, tools and grain storage structures. The break up of families into simpler units is contributing to increased dependent-per-worker ratios, with resulting poorer net worth and cash liquidity levels.

Family members tend to provide most input on the family farm (Figure 7.4). However, seasonality of agriculture in this farming system creates two challenges: labour bottlenecks during the rainy season and underemployed labour during the dry season. Traditionally, most

Table 7.2 Farming system features at the household level

Feature	Mali	Ghana	Nigeria
Family size (persons)	22	8.8	7.5
Age of head of family (yr)		52	46
Males involved in farm work (%)	48		50
Females involved in farm work (%)	67		50
Literacy of heads of family (%)	41	6	48
Marital status of head (% married)	99	97	
Cultivated area (ha)	9.5 (7–18)	3.9 (3–5)	8.7
Cereals (ha)	7.0	2.0	
Grain legumes (ha)	1.0	1.3	
Roots and tubers (ha)	<0.1	0.6	
Cotton (ha)	1.2	<0.1	
Cattle number	23.5	8	19
Small ruminants	15	17	
Poultry		30	
Pigs	4	5	0
Members of farmers' organizations (%)	86	51	65
% hiring labour			58
% using mineral fertilizer	50	100	
% accessing credit	81	17	27

Sources: Bamire et al. (2010); Fofana et al. (2011); Franke and de Wolf (2011); Wiredu et al. (2010).

Figure 7.4 Household compound in Karaba area, near Bobo Dioulasso, Burkina Faso.

Source: Amir Kassam.

explicit farm expenditures have been for payment of non-family labour. Such payment was often in-kind, although payment is now increasingly in cash, paid by the hour and job. This has led to attempts to introduce institutional forms of credit, both short and medium term.

Trends and drivers of change across the farming system

Farming systems tend to evolve depending on the interaction of agroecological, social, economic, technological, policy and institutional factors. McIntyre et al. (2009) and Norman (2002) asserted that first, agroecology, and second, population density, are the principal factors that create and drive the diversity of farming systems, after which market access (now of primary importance), land reforms and income, among others begin to exert significant influences.

Population, hunger and poverty

About half the population in this farming system lives in abject poverty. In 2015 about 55 per cent of the rural population had a per capita daily income of less than US\$1.90.

At the household level, the rapid increase in population, decreasing farm size, increased inequality and farm intensification are often associated with a decline in soil condition and farm productivity. A significant proportion of the farm population living on 1–10 ha or less than 1 ha of land are undernourished or severely undernourished respectively (data from van Wesenbeeck and Merbis 2012).

Youth are seeking employment in urban areas. For example, in northern Kaduna, fewer younger people are entering farming; the majority are migrating to urban areas in search of better employment or business opportunities.

At the farming system level, in spite of the increase in population pressure, the farming system has been able to satisfy increases in food demand, and has been able to produce industrial raw materials such as cotton and, more recently, cassava for starch. The increase has been possible due to area expansion (increased cleared area), improved varieties and increased use of fertilizer inputs.

In effect, expansion has offset increased population and minimized/slowed the effect of decreasing farm size. While this farming system has more land available for further expansion than other farming systems in Africa, rapidly increasing population, declining soil fertility, occasional severe drought and lack of rural electrification, functional roads, health and finance services and education opportunities will constrain further expansion and intensification. Without change in farming practices, the prospects for meeting future food demands are of concern. This indicates that poverty and hunger will remain a problem in this farming system in the foreseeable future.

However, increased globalization and ‘prospectors’ looking for opportunities could accelerate change. Will farmers with experience in no-till-based tropical agriculture from southern Africa, Brazil or elsewhere begin developing farmlands in the high-potential savannahs of west Africa? Policy makers need to consider such possibilities and their implications including the consequences for smallholders’ access to land. Some well-meaning farmers from outside west Africa are already establishing farms and experimenting.

Natural resources and climate

Deforestation has been extensive and is likely to continue as the farming system expands under pressure from population, markets and farm intensification. Within existing areas,

smaller farms and associated intensification of conventional tillage agriculture have had deleterious impacts on soil fertility and soil health. As a result, traditional techniques of maintaining soil fertility through shifting cultivation (slash and burn), ring cultivation and fallowing are no longer suitable to sustain food production. Additionally, responses to mineral fertilizers are less than optimum and insufficient plant biomass is produced to replenish the soil. Consequently, the current system is unlikely to be sustainable environmentally or socially in the longer run, especially given the anticipated negative impacts of climate change.

This problem is not unique to this farming system – across most production ecologies in Africa, including the zones with higher rainfall, soil degradation continues at an alarming rate as a consequence of population and ecologically unsustainable management practices that reduce soil organic matter and soil biota, mine plant nutrients and contribute to rainfall runoff and soil erosion (FAO 2011a; Montpellier Panel 2014).

Micro irrigation is used in some areas, such as in Burkina Faso where it is very successful. Supplemental irrigation can greatly enhance productivity and incomes in sub-zones where water is, at times, a constraint such as during the short drought between bimodal rains, or to permit a second cool season crop at the end of the main monomodal season. Rural energy (diesel cost) is often too expensive for pumping tube wells if they are not shallow.

Land use competition is evident in the inland valleys, which are important for both local and watershed water quality and supply. The water quality need competes with intensification of agriculture. In many inland valleys, dams have been built to hold water for irrigation schemes downstream.

There is a small amount of agroforestry in the farming system. The most prominent is the extensive culture of shea trees in crop fields and fallow lands. Teak as a homestead ‘tree bank’ has been effective in Benin in providing income at times of emergency and celebrations. Agroforestry and aquaculture have largely untapped potential in the zone.

There is some evidence that excess rainfall over evapotranspiration during the humid period in the growing season has decreased. In general, the farming system is not well adapted to climate change, neither is it geared to mobilizing and delivering key ecosystem services such as clean water, carbon sequestration, erosion control, biological nitrogen fixation and biological pest control. Crop and soil management practices that increase soil organic matter and encourage rainfall infiltration, will improve adaptation to erratic and shorter rains.

Energy

Most smallholder farmers use hand cultivation, and the use of draught power (livestock) and mechanization is low. There are marked variations in fuel costs within the farming system, with some countries such as Niger having very low-cost petroleum products, while others such as Burkina Faso do not. There are prospects for increased mechanization given the medium size of farms, and especially in west Africa where the landscape is less hilly and countries have cheaper fuel. An increase in mechanization would increase production and free up time for household members to sell or value-add produce or seek off-farm income.

Fuel for cooking is sourced from wood collected on-farm or in forests (firewood, charcoal making), sorghum and maize stover and dung, and this has a negative impact on forests and crop residues/nutrient cycling. The current use of charcoal, especially the

large quantities moved to urban centres, is not sustainable. Since the early 2000s, many households have changed from wood to domestic fuel (e.g. kerosene, gas), and the use of domestic fuels is expected to increase as incomes rise and where petroleum products are cheaper. Home-level power for night lighting, televisions and phones is increasingly available in rural area by solar panels coupled to batteries. An increase in access to inexpensive kerosene and electricity would have a major positive impact on production, poverty and natural resources.

There is the potential to use cassava for future bioenergy (IFAD/FAO 2010). In Mozambique near Beira, cassava-based ethanol is produced to sell along with inexpensive ethanol stoves produced in South Africa. This could be a model for other energy-deprived countries.

Human capital/knowledge sharing/gender

In general, the services provided to producers are not adequate in quality and relevance, and not easily available to women producers, for example, access to land, finance, markets, education, extension and knowledge. As outlined earlier, education levels are low particularly for women, and women have less involvement in farming and farm business. These factors can act as severe constraints to improving social condition and sustainable intensification.

Many technologies developed in Africa through formal research systems, including for this farming system, were not adopted by farmers simply because, although they were compatible with the bio-physical environment, they were incompatible with the socio-economic conditions under which farming families operated. This lack of success led to the popularization of the farming systems approach and farmer participatory approaches in the 1980s in which farmers played a more active role in the research process (Collinson 2000; Norman 2002; Kassam et al. 2017). Adoption of a more integrated, holistic approach with strategic alliances of key stakeholders underpins new initiatives and innovation platforms such as Humidtropics, a CGIAR Research Program led by the International Institute of Tropical Agriculture (IITA). Similarly, the 'Grow Africa' partnership, founded jointly in 2011 by the African Union (AU), the New Partnership for Africa's Development (NEPAD) and the World Economic Forum, works to increase private sector investment in agriculture, and brings novel ideas and resources to address development needs for the zone. More recently, the Australian Centre for International Agriculture Research (ACIAR) has supported conservation agriculture-based sustainable intensification (CASI) that is implemented in a participatory and flexible fashion (as a bundle of options for adoption in a flexible sequence rather than a fixed package) to ensure a good fit with the different types and stages of development of each farming system.

Increasing membership of farmer groups in this farming system indicates that information exchange is occurring between farmers, at least in some regions. There are some positive examples of community and group action, such as the Tanghin Kossodo Women's cooperative where information exchanged through publications, training courses and study tours, as well as group support through a community of practitioners, has led to significant improvement in production and livelihoods through adoption of CA (Box 7.2).

Understanding and knowledge about ecological sustainability and sustainable production intensification of the farming system has improved considerably since the 1990s, through scientific research and farmer practice. However, integration and dissemination of this knowledge into practical farming has faced several barriers including intellectual,

social, lack of equipment and machinery, lack of development investment, and inadequate national policy and institutional support to farmers and service providers.

Introduction of television in rural areas has created awareness of alternative livelihoods and expanded expectations of youth who consequently want more for themselves and their own children. More recently mobile phones have improved information access, sharing and awareness of new opportunities and markets. These provide drivers for households to move to a future beyond subsistence living.

Box 7.2 Crop-livestock integration and village enterprises

The Tanghin Kossodo Women's Farmer Cooperative Group in the Oubritenga Province, Burkina Faso, participated in a large, pilot scale programme (2,000 farmers in 30 sites) to enhance crop-livestock integration using CA. Major activities included silage and livestock production, specifically traditional chicken production, small ruminant management and cattle fattening. Through participating in the project, women farmers' achievements included that:

- animals are now fed with locally produced silage and salt-lick supplement
- ewes maintain milk production throughout the year and Azaouak cows produce 10 litres of milk each day throughout the year
- the Cattle Fattening Action Group of the women's cooperative received contracts from entrepreneurs in Ghana to supply fattened cattle
- farmers now undertake continuous silage production for sale, generating extra income for purchasing further livestock and for educating their children
- living standards and community life have significantly improved in the Oubritenga locality, including additional financial resources to expand their agricultural production businesses.

Source: FAO (2009).

Science and technology

A number of technology developments have helped increase crop and livestock production and commercialization in the farming system. A good example is cotton, which was promoted through the provision of inputs such as new varieties, fertilizers, insecticides, herbicides, animal traction equipment, farmer groups' activities and extension support.

Other well-known examples are early-maturing, drought-resistant maize, dual purpose cowpea, tropical soybean, biological control of cassava mealy bug, improved rice varieties for irrigated production in Mali (see IITA and AfricaRice), and more recently CA practices using no-till, maintenance of soil cover, and crop diversification through rotations, crop associations and cover crops including dual purpose cowpea, mucuna and *Brachiaria* (FAO 2009).

The adoption of animal traction-based weed management in some areas permits farm families, traditionally limited by the area that they can weed and prepare for planting, to

expand the area cultivated. However, FAO, African Conservation Tillage (ACT) and others (Kassam et al. 2017; Sims et al. 2012) have reported that lack of knowledge on crop-input management and of new equipment such as no-till direct-seeders continue to be major constraints. Other constraints include lack of access to suitable genetic material for vegetables, oilseeds, legumes, forage and tree species, and inadequate storage facilities for some crops. Where adopted, improved farming practices have led to improvements in productivity and livelihoods (refer to System and subsystem performance section).

Markets and trade

The farming system has, for some time, been considered as one of the future bread baskets of Africa and has, historically, also been an important source of export earnings (Kassam and Kowal 1973; Kassam et al. 2017). Some key trends in markets in this farming system are shown below (in order of importance):

- Infrastructure and local roads have developed tremendously in the 2010s – and to some degree secondary roads.
- There has been a concurrent explosion of transportation resources (e.g. buses) allowing people to move, and increasing societal connection and purchasing power (small-holders have some access to utilities and trucks to move produce).
- Border handling and processing has been streamlined, resulting in less cost (including bribes) and time for supply chains.
- Continued improvement in infrastructure is expected.
- Africa-wide, there has been an improvement in information communication technology (ICT), increasing functional market access (see earlier).
- Because of the lower population density in this farming system and greater potential to produce surpluses, there is potential for greater market development and access.

Increasing population, rapid urbanization, higher incomes and changes in lifestyle are increasing the effective demand for agricultural products (Tiffen 2004). Diets of urban and non-agricultural rural consumers are diversifying away from the traditional food staples towards the incorporation of less coarse cereals – particularly rice and maize – as well as fruits and vegetables, new oilseeds such as soybean, and livestock products (poultry, dairy and meat).

There is substantial demand for meat in west Africa because of extensive urbanization. Consequently the demand for animal feed from cereals and soybean is expected to increase. The cost of nitrogen fertilizer plays a key role in feedstocks. Cassava, due to its lower requirement for nitrogen fertilizer, will likely replace some maize in the feed mills (Phillips et al. 2004). Cassava chips can be milled into a powder that can be mixed with other ingredients – such as soybean meal or other protein sources – to make a nutritious animal feed that is commonly supplemented with vitamins and minerals. Soybean protein, whose nitrogen comes from biological fixation, is likely to increasingly replace the protein from maize in feed systems.

There is intra-regional (inter-farming system) trade between countries, such as livestock trade between the cereal-root (e.g. Ghana) and agropastoral farming system, and crops between humid farming systems and Burkina Faso/Mali. The retail supermarket trade is evolving in many parts of Africa, and this is expanding market opportunities for high-value horticulture products, especially under irrigation in the cool season.

However, the effect of supermarkets is less in this farming system, which is less urbanized than others, with the major fruit and vegetable growing areas in west Africa outside the farming system.

In subsystem 1, groundnut, cotton and livestock used to constitute the bulk of cash income for farmers and service providers, but since the late 2000s the main cereals, pulses, oilseed, and root and tuber crops are increasingly serving as additional cash crops for the domestic market.

The market demand for cassava is also expanding somewhat (IFAD/FAO 2010; Truman et al. 2004), both for livestock feed (see earlier) and other uses. High quality cassava flour produced in Ghana and Nigeria can be used as a partial alternative to wheat flour and other starches in bread and confectionary.

Leaves from irrigated vegetable crops, including sweet potato and cassava, contain high percentages of protein and are a valuable source of iron, calcium, and vitamins A and C. Where irrigation is possible, vegetables provide great potential profit, especially for farmers located close to urban areas.

Despite improving infrastructure and roads in the 2010s, the time and cost to transport root crops to market and the quality of the road system remain barriers (Table 7.1). For example, in Western Cameroon it is not uncommon to see food crops rotting by the roadside, which are scarce and expensive in Douala, 200 km away. In contrast, when the all-weather road from Kano to Zaria in northern Nigeria was completed in the early 1960s, it immediately stimulated a dramatic increase in the output of chewing cane and vegetables to meet existing effective demand, completely independent of any research or extension activities.

The transport problem is acute in the case of cassava. Although it does not have a specific harvesting period, it has a very short shelf-life after it is harvested. Thus, rural producers and markets have to consider the whole supply chain, including transport infrastructure. Household profitability can improve where transport is better, or there are opportunities for commercial supply or local value-adding.

The farming system is on the cusp of an operational change to generate value-added products increasingly demanded by rural and urban populations and industry, both for domestic and/or international markets. The growing markets for protein concentrates and vegetable oils, coupled with the need for a rotation crop that enhances cereal crop productivity, make the expansion of soybean cropping very logical. The inclusion of cassava in feed formulations is providing market price stabilization and income opportunities from this food security crop. New yellow-fleshed sweet potatoes too have both food and feed markets.

African farming systems have attracted considerable international investment and large-scale land acquisition has become significant (Cotula 2011; HLPE 2011; Schoneveld 2011) with African land representing up to 60 per cent of the estimated 80 million ha of land acquisition globally (Bruntrup 2011). In relation to the cereal-root crop mixed farming system, the countries that have attracted most investors include Nigeria and Ghana, with a large number of other countries involved to a lesser extent. Although such investments can provide much needed capital for Africa's agricultural development, there are socioeconomic and environmental risks such as accelerating forced migration to towns and cities, land degradation and disruption of ecosystem services (Bruntrup 2011), especially where governance structures are not strong. In some countries (e.g. Ghana) these land investments have clashed with existing farmers. Moreover, since most of the land is

leased to investors for renewable periods of 25–99 years, this may constitute long-term alienation of vital livelihood resources. A related concern is that huge amounts of hardwood trees are being extracted without reforestation, including in the cereal-root crop mixed farming system.

Policies and institutions

The actions and policies of both African and foreign governments in the recent past have led to many social, environmental and human problems in African nations, including indebtedness, inflated exchange rates and undue dependence on exports in ways which unsuccessfully continue colonial economic relationships.

Policies and practices which have had positive impacts on the farming system include Nigeria's disincentives (tariffs) for importation of feedstocks, which ensures competitive markets for locally grown maize and soybean. Implementation of appropriate policies can further stimulate domestic food production and investment in rural infrastructure. Kofi Annan noted: "Investing in infrastructure will certainly be expensive. But at least some of the costs of filling Africa's massive infrastructure financing gap could be covered if the runaway plunder of Africa's natural resources is brought to a stop" (Kofi Annan in Africa Progress Panel 2014).

In the years up to 2015, there has been some investment in markets and roads but not irrigation (there is potential for future development of all of these). There is declining government investment in technology, farmer education and extension, as in most of Africa. Investment is declining rapidly in extension, and significantly in research.

Public and private sector institutions also have an important impact on the farming system. Three crops that stand out in terms of private sector involvement are: cotton in farming subsystem 1, and maize and soybean in both farming subsystems 1 and 2. Private-public sector partnerships could also bring about sustainable livestock intensification in the zone, perhaps looking to recent experiences in analogous zones in Brazil.

System and subsystem performance

In general, crop yields in the farming system are slowly increasing – rapidly for cowpea and maize, slowly for sorghum, and not increasing for cassava and root crops. The capacity of the farming system to increase production with appropriate management has been demonstrated during the adoption of cotton, soybean and early maturing maize with associated changes in practices (Figure 7.5).

Although poorer households in subsystem 1 grow cotton with no or few inputs, most cotton farmers in Francophone west Africa grow cotton as part of regulated production schemes with moderate levels of inputs. The liberalization and globalization of the cotton trade calls for further improvements in the competitiveness of cotton production, by reducing the costs of production and raising factor-productivities and yields.

In the case of maize, west Africa achieved the fastest rate of production growth in Africa, with annual increases of 4.5 per cent between 1975 and 1999 (Byerlee and Eicher 1997), with much of this expansion occurring in subsystem 1 where rainfall is relatively reliable, which reduced the risk of investing in inputs such as fertilizer. The price collapse of 2000 has largely recovered and production is growing at nearly 7 per cent in west Africa (Coulialy 2014).

Figure 7.5 Influence of farming practice on cotton yield in West Africa 2010–2011.

Source: Settle et al. (2013).

There is good agroecological potential for improving production, but to do this sustainably will require adoption of ecologically sustainable production systems and practices, especially with respect to soil health and achieving more output from fewer inputs. The main constraint to increasing livestock productivity and output is the lack of adequate supplies of good quality livestock feed in the dry season produced at a competitive cost without jeopardizing household food security. Destocking is not popular, since livestock is considered a capital stock where the number of heads is more important than actual production. In terms of crops, simply applying intensive mechanical tillage and external purchased inputs may not achieve the desired long-term gains, particularly if soils require rehabilitation and/or close nutrition management for integrated farming.

Strategic priorities for the system

Population, hunger and poverty

Africa's population growth rates are already among the highest in the world and projections are for a four-fold increase by 2050. Consequently, the key priorities to address population, hunger and poverty are culturally sensitive policies to encourage birth control, alongside education on family planning, and programmes on better agriculture and food

systems. For the latter, more sustainable and integrated production systems, opportunities for intensification and value-addition, better distribution of produce between localities, and jobs outside farming to supplement household income, will all help improve household resilience, food availability and access.

Natural resources and climate

For small-scale farmers in subsystem 1, improved water management together with drip- and micro-irrigation can greatly enhance overall production, particularly during the dry season. This allows vegetable and dairy production resulting in improved diets and farm income. This potentially also applies to medium- and large-scale farming in higher fertility areas in subsystem 1. In larger-scale farms, investment in the use of central pivot, overhead sprinkler systems (common in commercial farms in analogous agroecologies in Latin America), may make sense when coupled with CA approaches and integrated crop and livestock systems. In locations with ample shallow groundwater and where energy is modestly priced, tube wells with efficient pumps, including axial flow pumps to move surface water to the fields could assist sustainable intensification of production systems. This approach is gaining traction in the Indo-Gangetic Plains in Eastern India (SCISA 2015) and could be tried in selected sites of the cereal-root crop mixed farming system in Africa. Water ponds with axial flow pumps for supplemental irrigation are gaining popularity in Central America, but are not commonly seen in this farming system in Africa.

The cereal-root crop mixed farming system has many climatic and edaphic similarities to the 'Cerrados' of Brazil, where agriculture has flourished since the late 1970s. In that region, CA, appropriate mechanization and farmer cooperatives have achieved significant improvements.

In the cereal-root crop mixed farming system, rehabilitating degraded soils, and better crop, soil and livestock management are critical to optimize biomass production to better meet the diverse demands for food, feed, firewood and fibre. This will require enhancing soil organic matter and soil health, including fixing nitrogen biologically. Fortunately, soils of African savannahs are less acidic than most Cerrados soils. Pilot schemes evaluating no-till CA systems in the farming system in Ghana, Burkina Faso, Cameroon (FAO 2009; Lahmar et al. 2012) and elsewhere in Africa (Marongwe et al. 2011; Owenya et al. 2011; Thierfelder et al. 2013; World Bank 2012) have shown that transformations are possible.

The farming system also needs to become more climate-smart, that is, adapt to climate change through biological soil health management, moisture capture and retention, and root system development that can support stronger resilient plants. Appropriate mechanization can facilitate adoption of these practices, by using CA principles, specific no-till direct seeding equipment, and precision farming technologies which reduce the use of inputs and the danger of soil compaction. Such systems can also mitigate climate change by sequestering soil carbon, thereby reducing emissions of greenhouse gases from the soil.

In the Brazilian Cerrados, organized community cooperatives have assisted with farmer learning and found solutions for grain handling. In the African farming system, often middlemen traders buy farm-gate grains at low prices. Family-farmers, with few options, are frequently vulnerable to such exploitation. Farmer cooperatives and centralized drying and grain storage strategies could improve farm returns, but these are constrained by the economics of hauling and inadequacies of rural roads. Perhaps public-private sector partnerships need to be found in each African country where this farming system is important.

Energy

Policies and markets that support increased access by rural householders to non-biomass energy (e.g. small-scale energy sources based on solar and batteries), electricity, petroleum fuel or renewable sources for domestic uses, and increased use of mechanized farming are required. Grain drying can be solar assisted but other power sources are required for rainy days. Power for pumping supplemental irrigation water is a must for reliable sustainable intensification. Cassava is being considered for bioenergy, especially in Ghana (IFAD/FAO 2010).

Human capital and information

The need to rehabilitate soil and reduce land degradation has implications for the extension and innovation system, for training of extension agents and farmers, and for management of crop-livestock integration at farm, community and watershed scales. Expanding farmer learning in soil health and sustainable agroecosystem management are ‘musts’ for governments concerned with food security, sustainable intensification and rural livelihoods.

However successful introduction is challenging, given that CA is knowledge and management intensive and requires change to the whole farming approach. Simple demonstrations, without direct farmer involvement in learning and discovery, will not be adequate. A phased approach tailored to the different circumstances and adoption capacities of farmers is more likely to be widely accepted and adopted. Empowering farmers through participatory techniques and fostering strong linkages between farmers, extension and researchers will be important in initiating and nurturing adoption. Delivery methods can build on the membership of farmer groups outlined earlier. Well-run Farmer Field Schools, such as those assisting adoption on IPM in Francophone west Africa, merit serious consideration for the introduction of CA systems.

Investment in trained ‘service providers’ who can contract direct seeding (preferably into no-till soils) and apply appropriate inputs, may be the best way to support appropriate mechanization. The service providers should be trained in CA and own the equipment for contract sowing (no-till direct seeding), as it is not feasible for most smallholder farm families to own and maintain the equipment required. Such ‘revolutions’ are underway in smallholder-based agriculture in eastern India. The agricultural machinery industry can also train some keen farmers to become service providers and trainers of trainers.

Broad adaptation and adoption of system approaches, including no-till CA, will depend on long-term investment in knowledge transfer. One advantage for Africa and the cereal-root crop mixed farming system, is that most farmers have experience in both cattle management and crop production. The diverse providers of information need to self-organize networks and be involved in broad programmes to adapt the science and technology for farmer adoption. Such multi-stakeholder innovation networks can include international agencies, multi-donor programmes, NGOs, national government staff, academic institutions, commercial organizations and agribusiness with their diverse points of view. Recent commitments by Brazil through EMBRAPA and other institutions, along with private sector involvement, could help jump-start sustainable intensification in the African cereal-root crop mixed farming system.

There is also a need to improve youth and adult education levels in the rural population, including women, to improve the opportunities for future employment and food security (Figure 7.6). As well as integrated farming, there is a particular need to increase capacity in value-adding, market trade and small business operation.

Figure 7.6 Cassava farmer from Oyo State, Nigeria.

Source: Judee Fisher.

Another key need is for governments to support agricultural research and extension through initial training of professionals, and subsequent long-term resources, including adequate salaries and operational costs to enable them to work with farmer organizations on farmers' fields. The current practice of expecting externally funded projects to provide the bulk of operational capital is not reasonable or sustainable. Closure of externally funded projects, even after promising short-term benefit, results in immediate collapse of national capacity to support farmers and a total disruption of work that requires continuity to bear fruit.

Science and technology

Some key research and development needs for this farming system include:

- striga control and management, including effective implementation and enforcement of existing policies
- aflatoxin reduction – promotion by governments of new technologies under the banner 'Aflasafe' that greatly reduce the incidence of toxins; farmers who produce toxin-free grain should be given meaningful financial incentives

- 60 day cowpeas and tropical soybean (based on research by IITA adoption has spread fairly fast) and other legumes to support diversification
- locally specific adaptation of CA practices including appropriate mechanization
- improving livestock integration including with crops, fodder production, rotation of pastures to break cropping, crop disease management, soil restoration and use of crops to fatten livestock
- extension and research that builds on the existing research on soil fertility and land management, livestock integration, feed, fodder and disease in this farming system, especially north of the *trypanosomiasis* zone
- storage, processing and marketing of root and tuber products, including for livestock feed
- short fallow management to clarify best-bet options for increasing total biomass production without decreasing the income flow to the farm family
- integrating tube wells and/or ponds to provide supplemental irrigation to extend the season and for winter vegetables.

Governments must provide meaningful and uninterrupted national plant breeding programmes to select and distribute crop genotypes and practices that are better-adapted to the actual climate, evolving farming systems, climate shocks and climate change. This should include crops not handled by private sector breeding programmes, for example cassava, sweet potato and yam improvement.

Publicly funded research should also address the increased risk of soil degradation in the humid and sub-humid savannahs, which will require long-term research on sustainable soil, agroecosystem health, agroecological system approaches and appropriate practices. Greater adoption of CA will require locally specific adaptations along with extension to train farmers in the necessary knowledge and management expertise (Kassam et al. 2017).

Existing efforts to encourage smallholder adoption of mechanization must be expanded, including the use of no-till direct seeders, herbicide sprayers and two-wheel tractors. In India and Bangladesh, two wheel single-axle tractors coupled to locally built trailers are helping to reduce the drudgery of crop and input hauling. Relatively small no-till planters, coupled to two-wheel tractors, have also become popular. In the cereal-root crop mixed system, individual smallholder farmers are not likely to own such equipment and there are agribusiness opportunities for service providers to contract plant (preferably no-till) and use two-wheel tractors to unlock constraints for farmers. Reaper cutter-bars, coupled to the same two-wheel tractor-based equipment, can also be used for cutting hay crops for livestock feed. Where this innovation is available, managed pastures could be revisited as a crop rotation option. Soil health of the soils would benefit greatly from mixed pastures in the rotation. Mechanization research for the needs of smallholders in Africa is sorely needed and should be prioritized by the CGIAR and NARS in collaboration with agencies such as FAO, NGOs and the business sector.

The farming system has a diverse range of pests, given the range of crops that are grown. Insect pests are exceptionally difficult for cowpeas, which originate in Africa. Soybean was until recently relatively disease and pest free in Africa, but infection with Asian soybean rust has made the selection of tolerant varieties, and in some cases use of fungicides, necessary. The parasitic weeds striga in maize and alectra in groundnuts are increasingly problematic and will continue to be constraints if soil health (mostly soil organic matter) is not improved. Cassava virus problems continue to be a challenge. Cassava mosaic virus has been largely contained, but cassava brown streak (CBS) has since

the late 2000s been causing major losses in eastern and southern Africa. If and when CBS reaches west Africa, the implications will be dire unless better management is identified. The biological control of cassava mealy bug by introduction of predators from Latin America remains a major success story of IPM in Africa.

The importance of integration has been explained in previous sections. There are a variety of integrated strategic interventions which warrant attention in this farming system. The System of Rice Intensification (SRI), originally developed in Madagascar in the 1980s, offers an agroecological approach that is more productive than conventional flooded rice and requires less input of seeds, water, nutrients and pesticides. Since the early 2000s, SRI has spread and shown benefits in the farming system in Gambia, Sierra Leone, Mali, Burkina Faso and Cameroon, as well as elsewhere in Africa (Kassam et al. 2011; Uphoff et al. 2011). Similarly, successes in raising productivity have been reported for NERICA (New Rice for Africa, developed by AfricaRice) rice in the tillage-based upland cropping systems, for example in Guinea and Burkina Faso.

IPM promotes the use of natural enemies to control pests, so that the use of pesticides is kept to a minimum. In subsystem 2, the IPM approach is being applied to tillage-based farming such as cotton, and to integration of soybean into the cropping system. In subsystem 1, it has also had considerable success, for example in Burkina Faso and Mali (Settle et al. 2013) through integrated crop-nutrient-pest management in tillage-based smallholder systems, and has reduced pesticide use in cotton, rice and diverse vegetable crops.

Another key integrated farming system solution, introduced earlier in the chapter, is CA, which is based on three principles: (i) permanently minimize or avoid mechanical soil disturbance (no-till seeding and weeding); (ii) maintain a continuous soil cover of organic mulch with crop residues and cover crops; and (iii) grow diverse plant species in cropping systems, all contributing to enhancing soil quality, system resilience, ecosystem services and sustainability. In other parts of the world with similar characteristics, CA has proven over time to increase soil organic matter levels, health and water holding capacity. This results in increased biomass production, resilience against adverse climatic conditions, improved livestock production and better integration of crop and livestock production in a controlled and managed way (Junior et al. 2012; Landers 2007). In Africa since 2008 more than one million hectares have been brought under CA (Kassam et al. 2013, 2015, 2017, 2018). In this farming system, the major attractions of CA are its potential labour-saving and increased efficiency in use of inputs. By integrating the CA technologies into maize, cotton, sorghum and cassava, system performance can be further improved and made sustainable.

CA should be relatively easy to adapt and adopt in the cereal-root mixed crop farming system, due to adequate rainfall, reasonable soils (if managed), and the suitability of the farming system to diversification, along with the larger fields relative to other farming systems. Where farmers have access to animal traction or tractors, rippers are used to open the planting lines for manual seeding, or no-till direct seeding equipment drawn by animals or tractors. Such systems have been employed successfully in mixed cereal cropping systems in the region and could also be used for root crops such as cassava (Howeler et al. 2013) and sweet potato.

Another opportunity to strengthen integration lies with agroforestry, whereby economically valuable trees can be integrated into both subsystems. The shea tree has been naturally regenerated and cultured across tens of millions of hectares in the farming system for many generations. Harvesting, processing and sale of shea nuts or butter is a major source of women's income. Demand for shea has been increasing rapidly, creating more

competitive markets and accelerated interest in the development of the industry. In areas where land is less of a constraint, farm families could put some land into fast growing trees such as eucalyptus, teak and rose wood. Economic harvest can take up to 10 to 15 years but in the long term farmers can attain financial security if fire can be controlled and farmers have long-term ownership of the land resource. Smallholder teak, for example, has been planted in several countries (e.g. Benin, Ghana). Ghana has an active agroforestry programme for the savannahs, with the implementation of incentives and support nurseries enabling farmers to plant and maintain trees as part of their farming system.

Leguminous trees and perennial shrubs can also be intercropped with crops. For example, cassava can be planted in alleyways between rows of deep-rooting and fast-growing leguminous trees, such as *Leucaena leucocephala* and *Gliricidia sepium*. In drier areas, deep-rooted trees compete less for water and nutrients than other intercrops. The foliage is cut back regularly and the prunings are either incorporated into the soil of the alleys, or in a zero-till system, applied as mulch before the cassava is planted. Leaf cuttings from forage legumes such as *Flemingia macrophylla* have a particularly positive effect on root yield of cassava (Howeler et al. 2013). Also successful are leguminous trees such as *Faidherbia albida*, with its loss of foliage during the rainy season. This means it does not shade crops, but instead provides nitrogen for the field crops through decomposition of its leaves (Evergreen Agriculture or 'CA with trees'; Garrity et al. 2010; Kassam et al. 2017).

The expansion of peri-urban poultry throughout the farming system and beyond, depends on feedstocks. There are opportunities for expansion of improved (planted) pastures as a rotation option with crops used for intensification of cattle for meat and dairy. Recently, efforts in Zambia have borrowed from models in the Brazilian Cerrados which use intensely managed pastures, often in rotation within CA's no-till annual cropping systems. There are many factors that will govern such transformations, such as access to land, seed, knowledge of the system and availability of no-till planters.

Along with supplemental irrigation, investment in grain drying and storage could also add important opportunities for intensification in production areas in subsystem 2 where the bimodal rainfall creates storage challenges.

Markets and trade

As outlined earlier, there are emerging markets for cereal, root and tuber and other crops in this farming system, in response to increasing population, urbanization and changing demands. This is stimulating domestic food production, increased value-adding and sale of feed for livestock intensification.

Market policies need to ensure that conditions enable all stakeholders to make a living. This includes creating infrastructure to reduce the costs of bringing inputs to farms, facilitate marketing of farm produce and allow transition from subsistence to income-generating farming and commercialized agriculture.

An essential problem is to change the risk environment so that smallholder farmers have the knowledge and decision processes to more proactively manage and engage with risk. This helps markets and trade to respond rather than being the result of smallholder farmers' risk-averse livelihood strategies based on previous experiences (Holden and Quiggin 2015). Value chain analysis can assess ways of improving business performance, product development, sustainability and greening the chain, opportunities for cluster developments, economic rents (how much money can be extracted from each stage of development) and governance structures.

Institutions and policies

Governments and public and private institutions must help establish and maintain an enabling environment to facilitate investment and agribusiness while protecting the natural resource base, environment and food quality and safety. Policy choices must both establish and maintain supporting infrastructure, research and services. Different public institutions need to be involved, including education, training, legal and financial. A key need is adaptation of local bylaws, including farmer rights to land and their access to crop residue/potential mulch on their land.

Further development of physical infrastructure (e.g. roads, bridges, power supplies, market structures) and communication infrastructure (e.g. phone systems, standardization of measurements, price dissemination) is required to facilitate input and output delivery systems and marketing. Electrification, well-maintained roads, finance, schooling and unbiased information are examples of domains where government inputs are essential. New solar-based rural electrical systems with contractual renting of power seem promising, but public and private sector investment is not yet adequate.

Government policy and implementation strategies are also needed (Kassam et al. 2017, et al. 2018) to:

- encourage access, via the private sector, to no-till mechanization equipment that is appropriate for small family farms in the farming system
- provide supportive services (roads, electrification) and research to facilitate uptake and spread of CA (Kassam et al. 2013, 2015) through new area-wide development programmes in economic/production corridors
- encourage small enterprises to provide farmers with seeds for cover crops and disease-free planting materials for major crops
- work with cooperatives to create credit based on farm-stored grain that can be held until sale prices are attractive to the farmer
- link diverse partners' goals and prioritize and facilitate win-win investments; needs of family farmers should be prioritized so that they can evolve to become more commercialized producers
- develop a supportive, enabling environment for the private sector to develop and operate the marketing functions.

While governments have primary responsibility for providing the infrastructure, experience in west Africa has shown that the delivery systems are best operated by the private sector (e.g. credit programmes, transportation, production and distribution of inputs, processing and marketing of products) and are more efficient if they are operated with as free a market as possible (Figure 7.7). With the increased commercialization of agriculture these can become very important employment generators. The private sector also has a significant role in equipment development (e.g. design and sales of no-till seeders). Similarly, there are opportunities for useful partnerships between the public and private sector to supply appropriate equipment and machinery to smallholder farmers.

A key input need is supply of seeds – in particular oilseeds and selected pasture, forage, tree and legume seed (including cover crops) suited to the dry sub-humid zone. There could be opportunities for specialized seed businesses involving smallholders, and especially women, with appropriate training.

Cooperation is required with other nations, international agencies and the private sector, in areas such as investment, trade, education, training, research and management

Figure 7.7 Private sector cassava processing for fermentation of ethanol, a fuel for cooking stoves that do not use wood.

Source: Judee Fisher.

of common interests. Some firms have made substantial long-term contributions to the development of nations and regions. Partnerships between African governments and private investment, including foreign, may help bring positive benefits to African agriculture and food systems, but governments must make sure that their countries share the benefits.

From a policy viewpoint countries should proceed very cautiously with large-scale land acquisitions. Balanced win-win solutions are needed so that the watersheds that feed the agroecologies are not destroyed and the host country shares the benefits. Under special conditions, judicious land acquisition could bring innovative, sustainable intensification of production systems. At the very least, protocols should be agreed to ensure such land is used in a sustainable manner and that the livelihoods and access to resources of local farmers are not jeopardized. Finally, large-scale land acquisitions should be integrated into the host country's broader rural development policies and strategies (Bruntrup 2011).

Relative importance of the five household pathways

In this farming system, intensification offers the greatest potential for farm households' escape from poverty and also for increased farm income for the less poor households. There is less opportunity for the poor to increase farm size, diversify crop and livestock production (the system is traditionally diversified), increase off-farm income or exit from

Table 7.3 Relative importance of household livelihood improvement strategies

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total ag pop	—	55	45	100
Intensification	3.5	3	4	3.5
Diversification	2	2	1	1.5
Increased farm size	3	1	3	2
Off-farm income	1	2	1	1.5
Exit from agriculture	0.5	2	1	1.5

Sources: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

agriculture (Table 7.3). Exit from agriculture is very dependent on alternative income sources arising from migration to urban areas. The exit strategy would become increasingly important: where farm sizes become smaller due to increased population density; where biomass production potential is lower (e.g. in drier areas); and as economies grow and become more diversified, offering wage employment and business opportunities for rural youth. One concern, which could force the involuntary exit of people from agriculture, could be allowing inappropriate large-scale land acquisitions.

Overall, it would seem that the prospects for agricultural growth and development are medium-high, and the prospects for poverty alleviation are medium. Growth through intensification is feasible because of the favourable agroecology and improvements in market access. Off-farm income has become more important since 2000, whereas for the poor the opportunities for expanding farm size have reduced (although this remains a pathway for the somewhat better-off households). Increasing numbers of poor farm households are expected to leave this farming system, especially for urban areas. For overall farming system development for poverty reduction or economic growth, the primary focus of policy and research should lie with intensification.

System conclusions

The cereal-root crop mixed farming system has, for some time, been considered one of the future bread baskets of Africa. Increased food production will require focused investments by governments and by the private sector. The potential for household poverty reduction appears to be good because of the promising agricultural growth prospects in the farming system (World Bank 2009).

Global effective demand for commodities such as cotton, groundnuts, soybeans, cow-peas, maize, cassava and yams as well as livestock have been driving agricultural intensification and diversification and will continue to do so in the future (IAC 2004; World Bank 2009). Opportunities to commercialize the farming sector will become even greater as economies become stronger, per capita income rises and the non-agriculture sectors increase effective demand for agricultural products. There are significant opportunities for intensification, given the adequate rainfall and soils (if well managed) and more choices in crop and livestock production relative to the farming systems to the north and south.

The huge potential for intensification of medium-scale agriculture (and larger food systems) could occur quite quickly given the larger average farm size relative to some other high-potential farming systems in Africa. Development of land markets and land tenure arrangements that allow farm consolidation would support this. Medium-scale farming is

often associated with faster adoption of new technologies and opportunities for private investment in seed inputs, purchasing, grain drying and storage facilities, and feed mills.

However, the continuation of current conventional tillage farming is likely, in the near future, to lead to a major decline in productivity because of the associated soil degradation. Fundamental changes in farming are required to enable soil organic matter to increase and resilient ecosystem functions to be restored. This can be achieved by using crop production methods based on the 'Save and Grow' principles of CA and precision farming, as well as IPM and integrated crop, nutrient and water management (FAO 2011b).

Government's role in enabling education, research and participatory extension, and rehabilitating degraded landscapes and ecosystem services, will become even more important in coming decades as greater pressures are put on the natural resource base. Some practices and innovations needed for sustainable intensification are knowledge intensive and require systems-appropriate management rather than reliance on purchased external inputs. For effective application of these innovations, farmers need participatory learning processes, trained facilitators and community organizers underpinned by effective strategies, implementation plans and funding. This calls for strong, publicly funded research and extension services.

Mechanization appropriate for smallholder farmers, supportive land policies (access and security) and efficient markets are also needed to improve the outlook for the farming system. Governments and the private sector can help enable these. Private sector dealers in appropriate mechanization need to be encouraged, alongside increased capacity, to ensure the correct use and maintenance of the equipment contracted out to smallholders.

Private sector investment is required in: science and technology (to match public input), communication resources, infrastructure (roads, electrification and other energy sources, grain storage), market information, transport, financial resources including credit, access to inputs, and emerging knowledge systems and other social services. Thus, an enabling environment for private agribusiness needs to be established, including government and private sector partnerships to establish infrastructure, services and markets. Novel approaches to holistic strategic planning are emerging in Africa, including economic corridor initiatives in zones with favourable agroecologies, for example in Ghana. The USAID-funded initiative of Feed the Futures is designed to harness such partnerships. New programmes such as 'Grow Africa' provide further opportunities for public-private investment in supporting infrastructure and institutions.

As the farming system evolves over the coming decades, far reaching changes will occur in farm size, number of farmers, farm mechanization, use of supplemental irrigation, grain drying and storage, and management of rural development and linkages between rural and urban economies. The technical and political challenges are reasonably well known. As African economies grow and diversify, the effective demand for food and other agricultural products will provide a basis for fostering sustainable intensification of agriculture. This must enhance food security and livelihoods, as well as rehabilitate degraded agroecosystems and provide ecosystem services for farmers, the community and society at large.

Notes

- 1 Inland valleys are the natural water drainage channels in the landscape, serving as source of domestic water as well as production environments for long-season crops such as banana and root and tuber crops in addition to rice and vegetables.
- 2 The tops (stems and leaves) of crop plants after the crop has been harvested.

References

- Altieri, M.A. and Nicholls, C.I. (2004) *Biodiversity and Pest Management in Agroecosystems*, second edition. The Haworth Press.
- Amaza, P., Abdoulaye, T., Kwaghe, P. and Tegbaru, A. (2009) Changes in Household Food Security and Poverty Status in PROSAB Area and Southern Borno State, Nigeria. IITA.
- Annan, Kofi (2014) Foreword. In Grain Fish Money Africa Progress Report 2014, Africa Progress Panel. www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Africa_Progress_Report_2014.PDF.
- Bamire, A. S., Abdoulaye, T., Sanogo, D. and Langyintuo, A. (2010) 'Characterization of maize producing households in the dry savanna of Nigeria'. *OAUIITA Publication* produced as part of the Drought Tolerant Maize for Africa (DTMA) Project Household Report: Household Survey. DTMA Country Report – Nigeria.
- Bruntrup, M. (2011) 'Detrimental land grabbing or growth poles? Determinants and potential development effects of foreign direct land investments'. *Technikfolgenabschätzung – Theorie und Praxis* 20(1): 3–12.
- Byerlee, D. and Eicher, C. (eds) (1997) *Africa's Emerging Maize Revolution*. Lynne Rienner Publishers.
- Collinson, M. (ed.) (2000) *A History of Farming Systems Research*. CABI.
- Cotula, L. (2011) *Land Deals. What's in the Contracts?* International Institute for Environment and Development (IIED).
- Coulibaly, L. (2014) *West Africa Cotton Producers Forecast Bumper 2014/15 Crop*. www.reuters.com/article/2014/10/16/cotton-westafrica-forecast-idUSL6N0S92AR20141016.
- Dixon, J., Gulliver, A. and Gibbon, D. (2001) *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World*. FAO and World Bank.
- FAO. (2008) 'Investing in sustainable crop intensification: The case for soil health', Report of the International Technical Workshop, FAO. *Integrated Crop Management* Vol. 6.
- FAO. (2009) 'Enhancing crop-livestock systems in Conservation Agriculture for sustainable production intensification: A farmer discovery process going to scale in Burkina Faso'. *Integrated Crop Management* Vol. 7. FAO.
- FAO. (2011a) *The State of the World's Land and Water Resources for Food and Agriculture (SOLAW): Managing Systems at Risk*. FAO.
- FAO. (2011b) *Save and Grow: A Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production*. FAO.
- FAOSTAT. (undated) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- Fernández-Rivera, S., Okike, O., Manyong, V., Williams, T.O., Kruska, R.L. and Tarawali, S.A. (2004) 'Classification and description of the major farming systems incorporating ruminant livestock in West Africa'. In Williams, T.O., Tarawali, S., Hiernaux, P. and Fernández-Rivera, S. (eds) *Sustainable Crop-Livestock Production for Improved Livelihoods and Natural Resource Management in West Africa*. Proceedings of an international conference held at the International Institute for Tropical Agriculture (IITA) Ibadan, Nigeria, 19–22 November 2001. ILRI, Nairobi, Kenya, pp. 89–122.
- Fofana, M., Abdoulaye, T., Coulibaly, N., Sanogo, D. and Langyintuo, A. (2011) 'Characterization of maize producing households in the dry savanna of Mali'. *Country Report: Mali*. IITA.
- Franke, A.C. and de Wolf, J.J. (2011) *N2Africa Baseline Report*. www.N2Africa.org.
- Garrity, D.P., Mowo, J.G., Akinnifesi, F.K., Ajayi, O.C., Weldesemayat, S.G., Kalinganire, A., Bayala, J. and Larwanou, M. (2010) 'Evergreen agriculture: A robust approach to sustainable food security in Africa'. *Food Security* 2: 197–214.
- HLPE. (2011) *Land Tenure and International Investments in Agriculture*. A report by the High Level Panel of Experts (HLPE) on Food Security and Nutrition, FAO.
- Holden, S. and Quiggin, J. (2015) *Climate Risk and State-Contingent Technology Adoption: The Role of Risk Preferences and Probability Weighting*. Working Paper No. 15 / 2015. www.researchgate.net/publication/282875706.

- Howeler, R., Litaladio, N.B. and Thomas, G. (2013) *Save and Grow Cassava: A Guide to Sustainable Production Intensification*. FAO.
- IAC. (2004) *Realizing the Promise and Potential of African Agriculture*. InterAcademy Council, Amsterdam.
- IFAD/FAO. (2010) *Global Consultation on Cassava as a Potential Bioenergy Crop*. IFAD and FAO.
- Junior, R.C., de Araújo, A.G. and Llanillo, R.F. (2012) *No-Till Agriculture in southern Brazil: Factors that Facilitated the Evolution of the System and the Development of the Mechanization of Conservation Farming*. FAO and IAPAR.
- Kamara, A.Y., Ajeigbe, H.A., Omolgui, L.O. and Chikoye, D. (2012) 'Intensive cereal-legume-livestock systems in West African dry savanna'. In Hershey, C.H. (ed.) *Issues in Tropical Agriculture Eco-Efficiency: From Vision to Reality*. CIAT, pp. 1–17.
- Kassam, A., Basch, G., Friedrich, T., Shaxson, F., Goddard, T., Amado, T., Crabtree, B., Hongwen, L., Mello, I., Pisante, M. and Mkomwa, S. (2013) 'Sustainable soil management is more than what and how crops are grown'. In R. Lal and R.A. Stewart (eds) *Principles of Soil Management in Agro-ecosystems. Advances in Soil Science*. CRC Press.
- Kassam, A., Derpsch, R. and Friedrich, T. (2018) Global spread of Conservation Agriculture. *Journal of Environmental Studies* (<https://doi.org/10.1080/00207233.2018.1494927>).
- Kassam, A., Friedrich, T., Derpsch, R. and Kienzie J. (2015) 'Overview of the worldwide spread of conservation agriculture'. *Field Actions Science Reports* Vol. 8, <http://factsreports.revues.org/3966>.
- Kassam, A.H. and Kowal, J. (1973) 'Crop productivity in savanna and rain forest zones in Nigeria'. *Savanna* 3: 39–49.
- Kassam, A., Mkomwa, S. and Friedrich, T. (eds) (2017) *Conservation Agriculture for Africa: Building Resilient Farming Systems in a Changing Climate*. CABI.
- Kassam, A.H., Stoop, W. and Uphoff, N. (2011) 'Review of SRI modifications in rice crop and water management and research issues for making further improvements in agricultural and water productivity'. *Paddy and Water Environment* 9: 163–180.
- Lahmar, R., Bationo, A., Dan Lamso, N., Guéro, Y. and Tittone, P. (2012) 'Tailoring conservation agriculture technologies to West Africa semi-arid zones: Building on traditional local practices for soil restoration'. *Field Crops Research* 132: 158–167.
- Landers, J. (2007) 'Tropical crop-livestock systems in conservation agriculture: The Brazilian experience'. *Integrated Crop Management* Vol. 5. FAO.
- Marongwe, S.L., Kwazira, K., Jenrich, M., Thierfelder, T., Kassam, A. and Friedrich T. (2011) 'An African success: The case of Conservation Agriculture in Zimbabwe'. *International Journal of Agricultural Sustainability* 9(1): 153–161.
- McIntyre, B.D., Herren, H.R., Wakhungu, J. and Watson, R.T. (eds) (2009) Sub-Saharan Africa (SSA) Report. *International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)*. Island Press.
- Montpellier Panel. (2014) 'No ordinary matter: Conserving, restoring and enhancing Africa's soils'. Report from the Montpellier Panel, at the International Fund for Agricultural Development, Rome, 5 December 2014. www.ag4impact.org/news/no-ordinary-matter-conserving-restoring-and-enhancing-africas-soils-2014.
- Norman, D. (2002) 'The farming systems approach: A historical perspective'. *Seventeenth Symposium of the International Farming Systems Association*, Lake Buena Vista, Florida, 17–20 November 2002.
- Norman, D., Beeden, P., Kroeker, W.J. Pryor, D.H. Hays, H.M. and Huizinga, B. (1975) 'The feasibility of improved sole crop maize production technology for the small-scale farmer in the Northern Guinea Savanna Zone of Nigeria'. *Samaru Miscellaneous Paper* No. 59. Ahmadu Bello University.
- Owenya, M.Z., Mariki, W.L., Kienzie, J., Freidrich, T. and Kassam, A. (2011) 'Conservation Agriculture (CA) in Tanzania: The case of the Mwangaza B CA farmer field school (FFS) Rhotia Village, Karatu District, Arusha'. *International Journal of Agricultural Sustainability* 9(1): 145–152.

- Phillips, T.P., Taylor, D.S., Sanni, L. and Akoroda, M.O. (2004) *A Cassava Industrial Revolution in Nigeria: The Potential for a New Industrial Crop*. IFAD and FAO.
- Schoneveld, G.C. (2011) The Anatomy of Large-Scale Farmland Acquisitions in sub-Saharan Africa. Working Paper 85, CIFOR.
- SCISA (2015) Website. www.iwmi.cgiar.org/Publications/CABI_Publications/CA_CABI_Series/Water_Productivity/Unprotected/0851996698ch15.pdf.
- Settle, W., Soumaré, M., Sarr, M., Hama Garba, M. and Poisot, A.-S. (2013) 'Reducing pesticide risks to farming communities: Adaptive management through Farmer Field Schools in the Senegal and Niger River basins in west Africa'. *Philosophical Transactions of the Royal Society B* 369(1639): 20120277. <http://dx.doi.org/10.1098/rstb.2012.0277>.
- Sims, B.G., Thierfelder, C., Kienzie, J., Friedrich, T. and Kassam, A.H. (2012) 'Development of the conservation agriculture equipment industry in sub-Saharan Africa'. *Applied Engineering in Agriculture* 28(6): 1–11.
- Thierfelder, C., Chisu, J.L., Gama, M., Cheesman, S., Jere, Z.D., Bunderson, W.T., Eash, N.S. and Rusinamhodzi, L. (2013) 'Maize-based conservation agriculture systems in Malawi: Long-term trends in productivity'. *Field Crops Research* 142: 47–57.
- Thornton, P.K., Kruska, R.L., Henninger, N., Kristjanson, P.M., Reid, R.S., Atiena, F., Otero, A.N. and Ndegwa, T. (2002) *Mapping Poverty and Livestock in the Developing World*. ILRI.
- Tiffen, M. (2004) 'Population pressure, migration and urbanization: Impacts on crop-livestock systems development in West Africa'. In Williams, T.O., Tarawali, S.A., Hiernaux, P. and Fernández-Rivera, S. (eds) *Sustainable Crop-Livestock Production for Improved Livelihoods and Natural Resource Management in West Africa. Proceedings of the International Conference held at IITA*. Ibadan, Nigeria, 19–22 November 2001. ILRI and CTA.
- Truman, P.P., Taylor, D.S., Sanni, L. and Akoroda, M.O. (2004) *A Cassava Industrial Revolution in Nigeria The Global Cassava Development Strategy*. IFAD-FAO.
- Uphoff, N., Kassam, A.H. and Harwood, R. (2011) 'SRI as a methodology for raising crop and water productivity: productive adaptations in rice agronomy and irrigation water management'. *Paddy and Water Environment* 9: 3–11.
- Van Wessenbeeck, C.F.A. and Merbis, M.D. (2012) *Africa in Maps. Data Repository of the Food Economy in Sub-Saharan Africa*. Centre for World Food Studies.
- Wiredu, A.N., Gyasi, K.O., Abdoulaye, T., Sanogo, D. and Langyintuo, A. (2010) *Characterization of Maize Producing Household in the Northern Region of Ghana*. Country Report: Ghana. CSRI/SARI-IITA.
- World Bank. (2009) *Awakening Africa's Sleeping Giant: Prospects for Commercial Agriculture in the Guinea Savannah Zone and Beyond*. World Bank.
- World Bank. (2012) *Conservation Agriculture: How Has Zambia Scaled It up from the World*. Bank Institute, in collaboration with TerrAfrica programme and partners. www.youtube.com/watch?v=ZW7TnH1cHWWw.

8 The highland mixed farming system of Africa

Diversifying livelihoods in fragile ecosystems

Tilahun Amede and Mulugeta Lemenih

Key messages

- The highland mixed farming system found in mountainous areas of north-west, north-east and southern Africa is heavily constrained by land degradation, high population density, small landholdings, poor infrastructure, limited market opportunities and limited community capacity to respond to external shocks.
- The system produces special mountain products, including wool, herbs, medicinal plants, highland fruits, organic products, in addition to basic food grains, meat and milk. There is strong interdependency between crops and livestock in terms of draught power, nutrient cycling, food security and ecosystem management.
- With climate change and increased temperature, the system and the associated water towers would become more fragile, with reduced water yield, recurrent drought and extreme events. There is a need for collective action for coordinated management of upstream and downstream systems for mutual benefit.
- Investment is required to enhance productivity to feed the growing population while maintaining/improving the ecosystem services. Targeted support is needed for system integration and resilience, including policies and strategies to add value and link mountain produce with niche markets, thereby facilitating positive livelihood change.

Summary

The highland mixed farming system occurs in the north-western, eastern, south-western and southern African highlands, hosting 73 million people on about 53 million hectares of land. The system is characterized by cool highlands more than 1700 m above sea level (asl) and a subhumid climate with an average length of growing period of 183 days. Mountainous and undulating terrain with valley bottoms and steep slopes dominate this system. There is a strong interaction between crop and livestock production. The four main subsystems (highland livestock-cereal, highland wheat-pulse, highland maize-based and highland mixed North African) are differentiated by socioeconomic and agroecological factors. The system is constrained by limited human and financial capital, and poor market access with at least 7.1 hrs travel to reach the nearest town with 50,000 people. High population density and growth, severe soil erosion, farm fragmentation, a declining

land holding per capita, declining soil fertility and overstocking are common traits. Only about 2 per cent of the rural population has access to power grids, while the majority depend on biomass energy. The energy demand is increasing the rates of deforestation, erosion and siltation of downstream investments, which exacerbates food insecurity. On the other hand, this farming system contains the 'water towers' of the region, and their conservation could trigger positive economic and social change in both upstream and downstream countries. The system also hosts more people and more livestock per unit area than the other African rainfed farming systems due to its favourable climate for people, crop production and livestock health.

The farming system produces distinct mountain products and services. Investment priorities include rural energy, facilitation of mountain niche markets (e.g. wool and mohair, highland flowers, organic honey), commercialization of livestock production, diversifying livelihood options (including on-farm and out-migration) and increased access to technological information and knowledge. Increasing use of information and communications technology (ICT), particularly mobile phones, has improved farmers' market access and negotiation power. Such infrastructure could also boost the tourism industry to provide an alternative income to the regions. Policy support to increase access to agricultural inputs and credit would help farmers to respond to emerging markets, gain some of the value currently captured by middlemen and invest in agribusinesses. However, this calls for strong institutional and policy support across scales to improve the organizational and brokering skills of highland communities and encourage them to pool their limited resources to achieve economies of scale, enter new markets, attract new resources and improve their livelihoods.

Introduction

The highland mixed farming system occurs in the north-western, eastern, south-western and southern African highlands more than 1700 m above sea level, in Morocco, Algeria and Tunisia (referred to hereafter as the Maghreb), Ethiopia, Lesotho, Cameroon, Nigeria, Angola, Eritrea, Mozambique, South Africa and Zimbabwe. The central plateau of Cameroon, dominated by the Adamawa massif, is a transition from the forests of the south to the savannah of the north, and is dominated by the highland mixed system. In the western highlands, the farming system includes areas surrounding Mount Oku, Mount Bambutos and the southwest regions around Mount Cameroon, representing about 384,000 ha. In Angola, the system occurs on the high plateaux to the east of the mountain range, including the Benguela Plateau and the Humpata Highland region of the Huíla Plateau, with altitudes up to 2500 m. In Lesotho, about 74 per cent of the country is mountainous highlands, including the Orange River valley, with a cropping area of 127,000 ha. In the Atlas Mountains in the Maghreb there are about 3 million ha high altitude cool to cold mixed crop-livestock farming. In Ethiopia, highlands cover about 450,000 km² or 44 per cent of the country. Overall, around 70 per cent of the land area of this farming system occurs in the Ethiopian highlands (Figure 8.1).

This farming system hosts 73 million people on about 53 million hectares of land. Population density is high and about 37 per cent of the population lives on an income of less than US\$1.25 per day. It is estimated the population will reach 87 million by 2030. In 2014, there were also about 32 million cattle, 32 million sheep and goats, and a considerable number of equines and other farm animals in the system.

Figure 8.1 Location of the highland mixed farming system and its four subsystem in Africa.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

This system has a subhumid climate with an average length of growing period of 183 days and an average rainfall of around 1155 mm yr⁻¹. Annual rainfall ranges from about 600 mm in the north-west of Morocco and the northern highlands of Eritrea, to over 2200 mm in the more humid highlands of Cameroon and Angola. Mountainous and rugged terrain with valley bottoms and steep farming dominate the system.

The highlands are characterized by mild temperatures, usually 18–22°C in the lower elevations and 10–12°C in the higher elevations (higher than 3000 m asl). However further south, Lesotho has a temperate climate with temperatures ranging from –12 to +35°C. The climate in Cameroon's wet savannah highlands is characterized by a long rainy season (April to November) and a short dry season (December to March) with annual rainfall varying between 1600 mm and 1750 mm, and an average temperature

of 22°C (Degrande et al. 2007). However, in the Atlas Mountains in the Maghreb seasonal temperatures are lower and snow is common in the winter. The highland mixed system across the continent usually experiences hailstorms, destroying much cropping each year.

Due to their cooler and humid climate, relatively good agricultural potential and lower incidence of pests and diseases affecting both humans and livestock, the highlands are preferred over the lowlands as places to live, attracting a higher population density. For instance, in Ethiopia 80 per cent of the population resides in the highlands, with population densities reaching about 700 persons per km² (CSA 2010).

The geology of the farming system is predominantly basic rocks, mainly basalts, while basement complex as well as metamorphic rocks, such as gneisses and marble, prevail in the mid highlands. With the exception of the Atlas Mountain area in the north-west of Africa, the soils of the African highlands are generally young, well drained and deep (except on eroded slopes and very cool mountain peaks), and considered to have good agricultural potential. However, the predominant soils are prone to erosion and leaching and are characterized by low cation exchange capacity. Where the annual rainfall is higher, so is the acidity of the soils. The wet savannah soils of Cameroon are dominated by ferralitic, while the Ethiopian highlands are dominated (85 per cent) by four soil types (Nitisols, Leptosols, Luvisols and Vertisols). In Lesotho, about 45 per cent of the soils are Andosols (of volcanic origin, high organic matter content and highly erodible) followed by highly developed Luvisols. Due to the undulating landscapes in this system, the valley bottoms are usually enriched by alluvial soils. The valleys serve as grazing areas in the dry season and watering points for people and livestock, particularly during the dry season. The general characteristics of the highland mixed farming system are presented in Table 8.1.

Table 8.1 Basic system data (2015): highland mixed farming system

<i>Item</i>	<i>Data</i>
Total human population (million)	72.5
Agricultural population (million)	44.5
Total area (million ha)	53.4
Cultivated area (million ha; % of total area)	13; 24
Irrigated area (million ha; % of cultivated area)	0.2; 2
Total livestock population (million TLU)	28
Major agroecological zone	Tropical cool subhumid
Length of growing period (average, days; core range, days)	183; 150–270
Access to services (low/medium/high)	Low-medium
Distance to 50k market (average, hr; core range, hr)	7.1; 2–10+
Agricultural population density (persons/total area; persons/cultivated area)	0.83; 3.4
Livestock density (TLU/total area; TLU/cultivated area)	0.53; 2.2
Standard farm and herd size (cultivated area/household; TLU/household)	1.6; 3.5
Extreme poverty (% of rural population)	37

Source: Refer to Table 2.4.

Note: Basic data refer to the sub-Saharan African areas of the farming system.

Overall description of the highland mixed farming system and subsystems

While some parts of the highland mixed farming system in Africa show commercial orientation, most areas are semi-subsistence in nature and dependent on traditional crop and livestock practices. The use of animal draught for tilling land and transportation is a century-old practice in Lesotho, Ethiopia, Eritrea and Morocco which is still dominant in 2015. Current transportation of agricultural produce is predominantly by horses, donkeys and especially women, men and children. Tillage practices do vary somewhat across the farming system. Most farmers use draught oxen to pull a locally made plough, although in Lesotho horses and mules are used as well – the power of the draught animal depends on its condition (body weight, nutrition and health). Hoe cultivation is practised in the highlands of Mozambique, Angola and Cameroon.

Across such high altitude landscapes in this system most of the land is used for grazing livestock. For example, in Lesotho only about 10 per cent of the land is suitable for crop production and the livestock sub-sector makes a major contribution to the economy – about half of agricultural GDP and a major share of exports, although its contribution to export revenue is declining (FAO 2005). In Ethiopia, the livestock sub-sector averaged 25 per cent of agricultural GDP and 11 per cent of national GDP between 1995 and 2006 (Negassa et al. 2011). In this farming system livestock are kept mostly for draught power. Their contribution to agricultural GDP could be as high as 45 per cent if the value of draught power is included (IGAD, 2010).

As can be seen in Table 8.1, the average farm size in the highland mixed system is about 1.6 ha per household and about 0.3 ha per person. However, farm size varies widely: the average farm size is only 0.4 ha per household for the poorest quartile in Ethiopia, and about 1 ha, 1.75 ha and 4.1 ha for the second, third and upper quartiles respectively (Shiferaw et al. 2013). The average landholding reaches 3 ha per head in Lesotho and Cameroon. Adoption of modern agricultural technologies is limited in the highland mixed system. However in wheat, where farmers can save and recycle the seeds, 68 per cent of households and about 65 per cent of the land uses improved varieties (Shiferaw et al. 2013).

High value crops including coffee, cocoa, peach, apple and other fruits are produced in some parts of the highland mixed system for sale and home consumption (Figure 8.2). Highland flowers and beekeeping are also becoming valuable enterprises. Sheep and goats are kept for generating cash and producing wool and mohair for fibre markets, with wool being a common product across highland regions. Crop types and rotations vary across the highland mixed farming system. The highland mixed system is an extensive crop-livestock system, where there is crop cultivation but low yields, extensive livestock production, low input use and poor connectedness to markets (Herrero and Thornton 2011). Few communities have evolved towards intensive systems as is the case in Baleke in the western Cameroon highlands. There is a strong interaction between crop and livestock enterprises; the livestock sector provides manure, draught power and often cash from sales to the crop sector, while crop residue is the major source of livestock feed.

Livestock feed is one of the major constraints across the farming system. Up to 70 per cent of the feed comes from crop residues, although ruminants graze on common property resources or in fields after the grain crop harvest. Crop residues and by-products are fed to livestock throughout the year or seasonally. Draught oxen and milking cows are given priority in supplementary hand feeding, particularly during the dry season and ploughing months.

Figure 8.2 Coffee agroforestry field planted in maize with banana and scattered fruit trees, western region, Cameroon.

Source: Christian Cilas.

Although farmers in the highlands are keen to improve their production including through use of external inputs, they rarely have access to credit, insurance and inputs. While the use of improved seed and chemical fertilizer in Ethiopia increased from 440,000 tonnes in 2008 to about 950,000 in 2015 (IFDC 2016), the amount of nutrient applied per hectare is still small, though on an increasing trend. Both the level of inputs and returns in terms of grain yield have been inconsistent and volatile (Chamberlin and Schmidt 2011).

There is an increasing out-migration from the highlands to cities and other countries in search of livelihood opportunities. The remittances received by farm households in the highland system have been enriching livelihoods and transforming some small towns.

The highland mixed farming system can be divided into four major subsystems, each with characteristic patterns of sociocultural attributes (e.g. food habits), farm size, crop type, farming practices (e.g. oxen plough vs hoe cultivation), livestock and grazing system and off-farm income that vary depending on factors such as local climate, land tenure system (private, public and communal holding), household strategies and, most especially, access to markets.

Highland livestock-cereal subsystem

This subsystem occurs in the uppermost dry highlands, and includes the frosty mountainous landscapes (Wurch) of Ethiopia, Eritrea and Lesotho, which lie above 3000 m asl in Ethiopia. The subsystem receives up to 2200 mm rainfall per annum depending on the

region. Temperature is generally low, with a mean of 14°C but varies with country. In Ethiopia, it ranges from below freezing to a maximum of 20°C with a high probability of frost at night, particularly in October and November. In Lesotho, temperature varies from –12°C to +35°C depending on the season. Frost, land degradation and erosion are major production challenges. Runoff leaves the system very quickly due to the steep terrain.

Livestock (mainly cattle, sheep and equines) is the major livelihood along with barley in Ethiopia (Figure 8.3), together with grazing cattle and small ruminants. Livestock are kept throughout the year on natural pasture, rangelands and crop stubble. Livestock, particularly small ruminants, play a very important role across this subsystem as a source of cash to buy food during bad years but also for purchasing agricultural inputs (e.g. farm implements and fertilizers), basic household necessities, school fees and paying government taxes. Manure is a major source of fuel and soil organic fertilizer for soil. However, the subsystem has low productivity (Box 8.1). For example, the annual per capita production of meat, milk and eggs in Lesotho decreased by 5 to 10 per cent between 1980 and 2002 (FAO 2005) and has continued to decline thereafter (Bureau of Statistics, 2013). The gaps are currently filled by imports from South Africa.

A bimodal growing season of 180–240 days in Ethiopia enables farmers to grow short season varieties during *belg* (small rains) and long maturing varieties during *meher* (long rains). Crop production is based on traditional practices involving draught animal plough, hand weeding and harvesting. Barley yield rarely exceeds 1.5 t/ha (see Table 8.3 later in this chapter). It is grown for food, for the local alcoholic drink (*tella*), for occasional cash sales and the straw to feed livestock. Potato is grown either as a relay crop or in mixture with barley. Potato production during the short rains is constrained by high prevalence of the disease late blight (*Phytophthora infestans*). The majority of farmers do not apply chemical fertilizers.

Box 8.1 A typical household in the livestock-cereal subsystem in the northern Ethiopian highlands

Yimer has a family of six and a farm size of 2 ha where he keeps livestock, mainly sheep, as the main source of income and food. He also grows barley for household consumption during the short (*belg*) and long (*meher*) rainy seasons, followed by potato. He uses oxen for ploughing and threshing while produce is either transported by donkey or on women's backs. Donkeys and mules play a very important role in reaching nearby markets. Frost is a major production problem followed by soil erosion, unpredictable rains and high input costs. He has limited access to information and extension services. He commonly experiences at least a month of food deficit per year and fulfils that deficit by selling sheep, retail trading or depending on food aid in the worst years.

Farmers are increasingly growing small patches of fruit trees and, in Ethiopia, enset (*Enset ventricosum*) in their home gardens. Despite the intense grazing pressure and deforestation, trees continue to play a critical role in ecosystem function.

This is the most food insecure subsystem, aggravated by lack of market opportunities, shortage of capital, poor communication infrastructure, poor institutional and

Figure 8.3 Livestock–cereal subsystem in the northern Ethiopian highlands.

Source: Tilahun Amede.

extension support, and limited off-farm income opportunities. Crop failure in this subsystem is commonly compensated by food purchases financed by selling sheep and goats, or in severe droughts through food aid. However, the trend is slowly changing as more and more farmers gain access to agricultural inputs. Road access and mobile connectivity are increasing despite the challenging terrain, which improves access to markets, technologies and information flows. Nevertheless, poverty within this subsystem is extensive, infrastructure is poorly developed and the degradation of natural resources is a serious problem.

Highland wheat–pulse subsystem

This subsystem occurs in the mid-level subhumid highlands, where wheat is the major food and cash crop, along with pulses and livestock (Figure 8.4). It is found in areas with an altitude of 2200 to 3000 m asl and rainfall ranges from 800 to 1600 mm per annum that is commonly bimodal. The growing period is 120–180 days. Typical minimum and maximum temperatures are 6 and 24°C.

This subsystem predominantly grows wheat with some barley, faba beans, oats, potato, peas, lentils, niger seed and flax. Like the livestock–cereal subsystem, households in this subsystem own livestock. However, in this subsystem temperatures are higher and cropping is much more diversified than in the livestock–cereal subsystem (Box 8.2).

Figure 8.4 Northern Ethiopian highland landscape of the wheat-pulse subsystem.

Source: Tilahun Amede.

Box 8.2 A typical household in the wheat-pulse subsystem in the northern Ethiopian highlands

Bulti has a family of seven and a farm size of about 1.8 ha, where he mainly grows wheat, faba beans, field peas, lentils, flax, niger seed and other oil crops. The fields are dispersed and allotted for different crops. He owns 6.2 TLU livestock including oxen, cows, a donkey, horse and shoats. He has a diversified farm where he grows various crops for food and markets. Niger seed and lentils are produced for market to cover household needs and paying taxes. There is an increasing agricultural investment in his surroundings (in few cases flower farming) and women are engaged in more off-farm employment. He commonly uses improved seeds and some fertilizer. He rarely experiences food deficit except in extreme years.

In relation to the bimodal rainfall pattern in the highland wheat-pulse subsystem, the mean crop yield in the long rain season usually exceeds that of the short season by about 30 per cent. During the long growing season wheat is the principal cereal crop, often over 40 per cent of the area allotted to cereals, whereas in the short season other crops (mainly barley) predominate. Although most farmers use traditional implements and practices, there is increasing use of tractors and combine-harvesters in the lower wheat belts, usually through short-term contractual agreements. Constraints to wider use of farm mechanization include lack of cash to purchase and/or hire farm implements, lack of access to purchase farm implements, land fragmentation aggravated by the steep terrain and lack of knowledge. Application of some chemical fertilizer has a relatively long history in this subsystem with some households beginning application in the 1960s (Spielman et al. 2011);

and the levels of application are increasing over time (IFDC 2016). A crop rotation with legumes commonly occurs once every two to three years. Hand weeding is common but labour shortage commonly constrains frequent and thorough weeding.

The highland wheat-pulse subsystem experiences the same challenges faced by the highland livestock-cereal subsystem, although enterprises are more diverse, institutional support is stronger and the diversity of agricultural commodities allows communities to better cope with climatic and market shocks. There is increasing use of external inputs and market-oriented farming through livestock fattening, beekeeping, formation of market cooperatives and improved market linkages.

Highland maize-based subsystem

This subsystem occurs in the mild subhumid highlands (Box 8.3, Figure 8.5), where maize is a dominant crop along with pulses, small grain cereals (e.g. teff in Ethiopia) and livestock. Altitude ranges from 1700 to 2200 m and annual rainfall from 600 to 1300 mm, leading to a growing season of 100–180 days. This complex subsystem produces the major staple crops including maize, sorghum and wheat in Lesotho, and maize, groundnuts and beans in Angola and Cameroon. In Ethiopia and Eritrea cropping is diversified, including teff (*Eragrostis abyssinica*), maize, wheat, faba beans, chickpeas and beans, along with livestock – the number of crops produced by farmers in this subsystem ranges from 4 to 14 different species. Teff is an indigenous crop, which is used to prepare *injera* (unleavened

Figure 8.5 Maize-based subsystem in central Ethiopian highlands.

Source: Tilahun Amede.

bread), the staple diet of many Ethiopians. It is attracting global attention for its gluten-free trait. However, maize accounts for the largest share of production and consumption. Sorghum is widely produced in this subsystem in Lesotho. In Cameroon and Angola, maize is produced along with yam, cassava and plantain.

The average size of a typical household is about six in number, with a landholding averaging about 1.0 ha in Ethiopia, while the landholding is larger in other countries, e.g. 2.5 ha in Lesotho. In Central Ethiopia, which has a relatively dense population, the farm size can be as small as 0.6 ha. Cereals are grown on about two-thirds of the farm, supplemented by pulses (beans, faba bean) and oil crops (niger seed, flax). Typically, an additional 0.5 ha of communal grazing land produces about 5.0 tonnes (dry matter) as fodder in a normal year. An average household in this subsystem owns 4.0, 0.5 and 0.7 TLUs of cattle, shoats (sheep and goats) and equines respectively (Hailelassie et al. 2009).

Application of chemical fertilizer in maize is increasing, with di-ammonium phosphate (DAP) and urea being the most-used fertilizer types. However, the Agricultural Transformation Agency of Ethiopia (ATA) has been promoting the use of blended fertilizers, informed by soil fertility maps throughout the country. Up to 25 per cent of the maize yield is harvested green for sale and home consumption, while the remainder is harvested as grain. Livestock plays an important role in this farming system too, predominantly in Cameroon, Lesotho (Figure 8.6) and Ethiopia. In Eritrea, about two-thirds of crop residues are used as livestock feed, with straw from small grain cereals and legumes being the most valued feed. However, due to the increasing feed deficit, livestock possession is declining in this subsystem.

Figure 8.6 Herder with mixed herd grazing at the Lets'eng-la-Letsie Ramsar Wetland site, Lesotho.

Source: Tony Palmer.

In general, this subsystem is considered the bread basket of the highland mixed farming system and hosts the majority of the population and has good soils and adequate, well-distributed rainfall. The mild warm climate allows relay- and inter-cropping. This subsystem produces many vegetables and fruits, often under small-scale irrigation. There are more opportunities to intensify crop-livestock systems and to respond to market demands than the above-mentioned examples. There is already a strong diversification and intensification trend in favour of market crops, particularly around towns and cities.

Box 8.3 A typical household in the highland maize-based subsystem in the central Ethiopian highlands

Birhanu has a family of six and a farm size of about 1.2 ha, where he mainly grows maize and teff in rotation with pulses such as chickpea, faba beans or field peas. The fields are fragmented and allotted for different crops. He grows up to 12 crops per season. Rainfall variability is relatively low, and soils are fertile and less prone to erosion. He owns 5.6 TLUs of cattle, shoats and equines. He is also involved in small trade, and one of his family members seasonally migrates in search of off-farm jobs particularly in cities and sugar estates. He uses oxen for ploughing and threshing while transport of produce is either by donkeys or mules. Teff is the major cash crop followed by chickpea. His family is food secure, except in extreme events. This is due to the crop diversity, being able to produce high value crops such as teff, and off-farm income.

Highland mixed north African subsystem

This subsystem occurs in the Atlas Mountains of the Maghreb region of north-west Africa, concentrated in Morocco with extensions (not mapped in Figure 8.1) into Algeria and the north-west corner of Tunisia at altitudes above 1700 m. The rainfall is lower than in the other highland subsystems and expected to reduce with climate change, perhaps by 5 per cent by 2050 with diminished spring rainfall and increased frequency of droughts. Land degradation is extensive and the steep slopes cause intense runoff and local floods from storms.

The Berber communities face physical and sociopolitical challenges which exacerbate poverty. Their survival and food security depends on the local natural resource base, traditionally supplemented by remittances. These marginal groups have limited options, which are under severe pressure because of globalization. The agricultural practices of the Berber communities are largely traditional. The major food grain is barley, which is relatively drought and disease tolerant and often grown on narrow irrigated terraces or valley bottoms. Water resources for humans, livestock and irrigation are scarce and risky. Remnant forests provide biomass – wood for building, cooking and heating, and forages for livestock. Almond and walnut trees are common.

Livestock (cattle, sheep and equines) play a key role in the subsystem, for which the availability of feed and forage is the principal constraint. Communal grazing of rangelands is an important livestock management strategy. Herders migrate seasonally between the lowlands in the more humid winter season and the highlands in the warm dry season.

The collection of supplementary fodder is a time-consuming task for women, especially in the winter. Manure is a major source of fuel and soil organic fertilizer for soil.

Regardless of the metric, the subsystem has low productivity, exacerbated by limited rainfall and low temperatures especially in winter in the Maghreb. Household livelihoods are precarious, and cash income is low. Remittances from off-farm work are a major source of income (about half of males work outside their district), which is supplemented by traditional income sources such as almonds, walnuts, carob pods and aromatic plants.

Trends and drivers of system change

The following paragraphs and Table 8.2 highlight major trends and drivers of change for the highland mixed system.

Table 8.2 Key drivers of change, trends and the implications for highland mixed farming system

<i>Drivers</i>	<i>Short- and long-term trends</i>	<i>Implications for farming system functions and needs</i>
Population and poverty	<ul style="list-style-type: none"> • Rapidly increasing population • Increased land fragmentation • Decreasing farm size • Expanding food grain demand 	<ul style="list-style-type: none"> • Challenge for mechanization and large-scale farming • Increasing challenge to feed the growing population • Need for diversification of livelihoods, including out-migration and remittance • Need for market incentives for intensification
Natural resources and climate	<ul style="list-style-type: none"> • Recurrent drought • Occasional flooding • Overexploitation of resources • Limited mechanization and use of inputs • Lack of management of risk and vulnerability 	<ul style="list-style-type: none"> • Need for improved landscape management • Need to build resilience to climatic and natural shocks • Need for strengthening collective action at community and higher levels that would improve landscape management • Land use policy and enforcement mechanisms would improve productivity and resilience of the system
Energy	<ul style="list-style-type: none"> • Household energy mainly biomass • Expanding electrification • Deforestation 	<ul style="list-style-type: none"> • Needed policy support and increased investment in energy supply and re-afforestation • Result would be more biomass available for soil fertility and other environmental services; more carbon sequestration and climate change adaptation • Improved rural mechanization
Science, technology	<ul style="list-style-type: none"> • Limited availability and use of inputs including biotechnology • Increasing access to information and knowledge, including mobile phones 	<ul style="list-style-type: none"> • More ICT information centres will be privatized and expanded • Regulatory policies for biotechnology would enable rural transformation • Farmers need better access to inputs to be able to produce more per unit of land, labour and water

Human capital	<ul style="list-style-type: none"> • Low but improving human capital 	<ul style="list-style-type: none"> • Possible shift of the agricultural labour force to skilled labour in cities and towns
Markets and trade	<ul style="list-style-type: none"> • Weakening rural economy • Poor but expanding road network • Improving market connectivity • Expanding market opportunities (crop, livestock and tree) and diversification and emerging niche markets 	<ul style="list-style-type: none"> • Improved market access with increasing urbanization • Need to establish regulatory and quality assurance mechanism for foreign markets • Need to develop niche markets for highland products • Need agribusiness investment in value chains • Functional livestock health regulations
Policies and institutions	<ul style="list-style-type: none"> • Usufruct rights but some changes to land tenure and land use policy • Lack of farmer confidence to invest in long-term land, water, forest initiatives • Lack of policy and institutional support for wetlands and fragile ecosystems 	<ul style="list-style-type: none"> • Needs include: • Sustained agricultural investment across scales • Subsidies for critical agricultural inputs to facilitate intensification • Policy enforcement mechanisms • Climate smart economy • Regional integration and economic corridors

Population

The African population is expected to double to 2.4 billion people by 2050, and the SSA population to swell from the current 900 million to 2.2 billion (*The Economist* 2014). Roughly 122 million young people in SSA will enter the labour force between 2010 and 2020, with slightly more than half of them from rural areas, putting immense pressure on both agriculture and non-farm sectors to generate employment opportunities (Jayne et al. 2014).

As the population increases, the demand for food, fuel and construction materials increases. In the highland mixed farming system the large population increase has led to a decline in forests, farm productivity and water availability, which has been leading communities to a downward spiral of poverty. This system is also under pressure from the rising demands of urban population, income shifts and resource degradation (Herrero and Thornton 2011). Although population growth is exerting heavy pressure on the farming system, few countries (e.g. Ethiopia) have designed a comprehensive population policy to deal with the issue.

Natural resources and climate

The rapid population growth in the highland mixed system is putting pressure on land and other natural resources. Population growth has led to expansion of cropped areas into mountainous rangelands, remnant forests and more marginal lands, and deforestation across all subsystems. Illegal logging is a major challenge in the Angolan and Cameroon highlands, causing erosion and downstream siltation; and in Cameroon, according to Gockowski et al. (2005), slash-and-burn agriculture is a major contributor to deforestation.

In Ethiopia the cultivated area has increased from 9.44 million to 15.4 million hectares between 2001 and 2009 alone (Abera 2010). Despite this expansion, farm sizes are in

decline, commonly ranging from 0.6 to 5 ha and averaging 1.6 ha. If the present trend in population growth (2.8 per cent per annum) continues without change in cereal production, Ethiopia's food per capita in 2025 would decrease by about 28 per cent (Ethiopian Economic Association 2000).

The location of the farming system on undulating and mountainous landscapes (with slopes ranging from 5 to 35 per cent), along with high rainfall intensity and recurrent deforestation, makes it susceptible to erosion. Estimated soil losses could exceed 100 t/ha while nutrient losses are estimated to be 80 kg of N, P_2O_5 , and K_2O per cultivated hectare per year (Smaling et al. 1997).

Erosion is the major environmental factor aggravating soil fertility decline, decreasing productivity, reducing soil carbon stock and diminishing environmental services. A quarter of the highlands of Ethiopia are seriously eroded (Amede 2003).

Importantly, the highland mixed system is found in mountainous highlands of Africa known as the 'water towers' of their respective regions, generating up to 90 per cent of the water reaching downstream countries. For instance, the Blue Nile, Atabara and Akobo rivers, which emerge in the Ethiopian highlands, supply up to 86 per cent of the water of Egypt and Sudan, while the Orange River from Lesotho's mountains is one of the major sources of water for South Africa.

The highland mixed farming system is also highly vulnerable to climate change. Climate change is increasing seasonal rainfall variability (Ali 2007) – up to 50 per cent in Lesotho – and the onset and offset of rains has become unpredictable, changing the farm management strategies and operations. The short rains have repeatedly failed; they used to produce about 30 per cent of the food and 40 per cent of the feed. Farmers are shifting towards short-maturing varieties, and some crop species which used to grow in warmer climates are now grown in the mountains. Some water reservoirs that used to satisfy irrigation needs and livestock drinking downstream are now drying up. Some communities are even discussing changing the names of the months in their local languages, as they no longer reflect the farming cycle.

It is predicted that extreme rainfall events due to climate change will cause sudden floods and storms that could destroy infrastructure downstream and wash away fertile soils, maturing crops, houses, farm investments and community assets. The impacts may be aggravated by low risk-coping strategies of communities and weak institutional capacities. The negative effects of drought are not only poor crop and livestock yield but also seasonal hunger, increasing conflicts, livestock death, migration of people to towns and an overall decline of the national economy.

Climate change will also affect the dynamics and epidemics of pests and diseases of crops, livestock and humans. Research reports indicate that a temperature increase of 2–3°C in these highlands could cause a higher population health risk, including a 3–5 per cent increase in malaria incidence (Argaw 2012). Other human diseases that could be aggravated by changing climate include Dengue fever, sleeping sickness and river blindness. Excess rainfall and flooding could also aggravate poor sanitation and cause more cholera, giardia and other water-borne diseases.

The effect of climate change on the system performance will be huge given the limited capacity of communities to carry high economic, social and environmental costs and risks. The only system that could benefit from increasing temperature due to climate change could be the livestock–cereal subsystem, which may achieve higher crop yields and pasture productivity provided the increased precipitation accompanies the rise in temperature.

Forests offer opportunities for land rehabilitation, environmental services and carbon sequestration, as well as income. In Cameroon, with forests and woodlands covering nearly 78 per cent of the country, the forestry sector is the country's second largest export earner after oil, generating around 20 per cent of export revenues, and it also provides significant farm income (Degrande et al. 2007). *Eucalyptus* has become an increasingly important source of cash for smallholder farmers. While cocoa is a major income source in the highland mixed system of Cameroon (New Agriculturist 2001), *Eucalyptus* species and khat (*Catha edulis*) have spread widely across the three subsystems in Ethiopia (pers. comm., Bekele Shiferaw, August 2013). In some zones (e.g. North Wollo and North Gonder) and near urban areas, eucalypts have overtaken livestock as a store of wealth, and farmers have converted some of their land to these fast-growing trees, which bring them highly valued cash.

Science and technology

There has been increasing investment in science and technology in the African highlands to develop and stimulate agricultural productivity over the last few decades. Though variable in research capacity and impact, national research systems have been developing improved crop varieties, livestock breeds, agricultural mechanization, post-harvest intervention and other technologies. Yet there is very limited growth in the agricultural sector or increase in crop and livestock productivity.

Mechanization is known to improve crop yield, labour efficiency, produce quality and overall system productivity. Use of mechanized ploughs commonly increases soil productivity, due to the mineralization of soil nutrients but also allows higher working depths and speeds. However, there has been limited development of mechanized commercial agriculture in the highlands to date, with fewer than 3,000 tractors operating in Cameroon and Ethiopia.

Although at various paces, national and regional research systems in the respective countries have been developing high yielding crop varieties in close collaboration with the Consultative Group for International Agricultural Research (CGIAR) centres. In some cases, the crop yield advantage can be as much as three-fold, particularly when varieties are accompanied by appropriate agronomic management and input delivery systems. However, these improved varieties are either rarely reaching the target users in sufficient quantity or are unaffordable. Moreover, these varieties also rarely receive the required fertilizer inputs (in terms of both quantity and type) and agronomic practices to produce their potential yield. Application of micronutrients to date is non-existent despite the fact that there is a huge land area in the highlands with calcareous and other problematic soils.

Highland farmers used to be isolated, with limited information sources outside their immediate network. But the situation is changing due to increasing access to radio and mobile phones. Radio stations have been important sources of information and technology for rural farmers, with regular programmes targeting farmers and extension workers. Recently, mobile phones have been providing multiple services to rural communities, including market information and mobile banking. Greater access to information seems to help highland farmers make better decisions about transportation and logistics, price negotiation, supply and demand, diversification of their product base and access to inputs (Dixie and Jayaraman 2011).

Markets and trade

The sustainability of this farming system depends in part on economic profitability that must provide for reinvestment in the maintenance of the ecosystem services and in satisfying the livelihoods of the people. Although small-scale farmers in the highland mixed system are keen to intensify and diversify, they are currently constrained by limited access to input and output markets. The challenging terrain and associated high cost of infrastructure development have been disincentives to develop roads and marketing in the respective countries to allow inputs and agricultural producers to move efficiently and economically. For instance, in the Ethiopian highlands the current all-weather road density (considering main, regional and rural roads) is below 15 per cent, with the average distance to an all-weather road being about 12 km (Shiferaw et al. 2012). The consequence is that it requires about 7.1 hrs to reach the nearest town of 50,000 people.

Construction of all-weather roads in mountainous terrain and escarpments costs several-fold more than on flat terrain and lowlands. However, market connectivity in Ethiopia is improving as the road density grew more than 70 per cent between 1997 and 2009, and the average distance to an all-weather road decreased from 21.4 km to 11.8 km (Shiferaw et al. 2012). Nevertheless, the vast majority of the highland communities are yet to be connected.

Public policies and programmes have played an extremely important role in shaping market conditions and private sector investment, in the context of the African Union's New Partnership for Africa's Development (NEPAD), the Comprehensive Africa Agriculture Development Programme (CAADP) and African trade blocks like COMESA (Common Market for Eastern and Southern Africa). However, efforts thus far have not fully unleashed the potential of private investment in agriculture (Nomathemba 2010), particularly in the more remote parts of the highland mixed system where market infrastructure is limited. Organizing and supporting malt barley growers and assuring them of market opportunities by beer companies in Ethiopia (e.g. Diageo), and creating rural job opportunities through highland flower farms also in Ethiopia, are two examples where the private sector has added value to the highland system.

There have been government attempts to diversify farming beyond cereals into higher value products, including fruits, livestock fattening, honey and vegetables. For example, in Lesotho, about 90 per cent of the farmers grow some type of vegetable and peaches are the major high value fruits. However, farmers' interest to intensify their farms decreases with distance from market. Those who live near markets opt to grow vegetables and fruits while those living in the remote mountains opt for food security and growing other non-perishable products.

Although trade and commercialization is an important driver in modernizing farming, many highland smallholder farmers do not participate regularly in big markets; for those smallholder farmers who do, the size of transactions (sale or purchase of cattle, sheep or goats) is very small (Negassa et al. 2011). Market integration could be realized if the products of small-scale farmers increasingly meet the requirements of the demanding and fickle markets, both at home and overseas. Changing the quality of produce would offer new opportunities to farmers who can successfully access and compete in such transformed markets, but they are also a serious threat to those who cannot (Hazell and Wood 2008). Organizing farmers' market groups has an important role, particularly in providing produce that satisfies market demands and in collectively negotiating prices, as was the case with wool and mohair producers in Lesotho.

Trade policies are also problematic: changes to import rules disrupt the stability and viability of domestic value chains; currency rules lead to foreign exchange shortages; and non-enforcement of agreed regional policy on property rights makes development of new technologies uneconomic (Grow Africa 2014). For instance, grain market liberalization has raised output prices for surplus producing areas, particularly in the last ten years. However, the marketing system across the highlands suffers from a limited number of inter-regional traders, limited financial capacity of traders to trade across regions, limited amounts of produce for storage in bad years, weak bargaining power of less organized farmers and very high handling and transportation costs (Ethiopian Economic Association 2000). Poor infrastructure within and between countries inflates transport costs and impedes the viability of trade.

The virtual absence of agricultural processing industries has further affected demand and quality of agricultural produce. SSA has experienced the highest urban growth of any region since the late 1990s at 3.5 per cent per year, and this rate of growth is expected to hold until 2050. Urbanization could expand the market opportunities for highland farmers and influence the production practices and intensification processes.

Policies and institutions

Historically, this system has received limited attention in terms of policy – and investment has been given mainly to areas where high value export crops (e.g. cocoa, sugarcane, flowers, coffee) are produced, or to large-scale irrigation farms (Mozambique). For example, in Cameroon, the state involvement in agriculture has been focusing on input subsidies for commercial crops, in this case cocoa.

The policy and institutional framework influencing the development of sustainable agriculture is well espoused by the NEPAD Comprehensive Africa Agriculture Development Programme (CAADP), which has recommended, as one of the four pillars, “extending the area under sustainable land management and reliable water control systems, especially small-scale water control, building up soil fertility and moisture holding capacity of agricultural soils and expansion of irrigation”. In response, the different countries where highland mixed farming is practised have given greater emphasis to agriculture through their national policies, although implementation of the policies varies. The Lesotho government has managed to allocate about 3 per cent annually towards meeting the target set in the Maputo Declaration on Agriculture and Food Security, which is to commit to allocate at least 10 per cent of the national budget to agricultural sectors. During the same period, Ethiopia allocated more than 10 per cent of the national budget to the agricultural sector (NEPAD 2009).

The Agriculture Development Led Industrialization (ADLI) policy and all subsequent plans and strategies including the three successive poverty reduction strategies – PSDP (2000–2005), PASDEP (2006–2010) and the recent Growth and Transformation Plan (GTP) (2011–2015) – have made agriculture their central emphasis. ADLI underlines that economic development through improving the agricultural sector should provide enough food for rural and urban dwellers, raw material for industry and increased income for rural communities. Additional policy changes include the abolition of quotas, the free movement of the labour force, an increased number of qualified agricultural extensions workers and a push for extensive introduction of technologies. Abolishing price controls could have a negative effect on farmers’ productivity due to price fluctuation over seasons,

creating more opportunities for the middlemen to take most of the profits at the expense of the producers (Ethiopian Economic Association 2000).

One of the policy challenges in the highland mixed farming system is how to improve labour productivity, given the current land use and land tenure regimes. The current fragmented land use system, where about 50 per cent of the farms in the highland mixed system are smaller than 1.5 ha, is a disincentive for agricultural mechanization and commercial farming (Ethiopian Economic Association 2000).

The land tenure policies of the governments, along with weak institutions, are often blamed for poor agricultural performance. Spielman et al. (2011) indicated that tenure influenced how farmers manage their land and water resources and make their short- and long-term management decisions. Land has remained as state-owned property in Ethiopia, Lesotho, Eritrea and Angola since the 1960s, and farmers have only usufruct rights. For instance, in Lesotho, the land tenure system is complex in that land belongs to the government, but the local chiefs are charged with administering the land on behalf of the government. The chiefs have the authority to confiscate underutilized farmlands and redistribute to potentially new clients. Under this tenure scenario, farmers are rarely keen to invest in management of land and water that they do not own. Ethiopia (since 2007) has established a decentralized land administration system similar to the land board system, with village land administration committees that allocate land within their jurisdiction, adjudicate disputes and implement policies for land use and administration (Holden et al. 2011). The requirements in terms of procedures are adhered to reasonably well (Abera 2010). The positive assessment of the programme's impact is supported by beneficiaries' views and their willingness to share the costs. Certification has also increased the probability of new investment in land and water management.

Land fragmentation due to high population pressure and land tenure policies is considered a limiting factor for expansion of mechanized, commercial agriculture in the highland mixed system. Commercial agriculture in the Ethiopian and Eritrean highlands to date has been dominated by government enterprises focusing on industrial crops, namely sugar cane, malt barley, wheat and oil crops. However, the attempt to expand commercial agriculture through state farms has failed in most cases, including in Angola and Ethiopia. There are recent attempts to integrate small-scale growers into these large-scale schemes.

In general, there is a need to develop climate-smart policies which will favour the most fragile ecosystems of the highlands. Lesotho has developed a climate responsive National Strategic Development Plan (NSDP) 2012–2016 (GCCA 2014), while Ethiopia has introduced a widely accepted strategy document on a climate-resilient green economy, which calls for reducing livestock carbon footprints, reducing deforestation and creating national capacity (UNCSD 2012).

Access to energy

Agriculture has a dual role both as an energy user and energy supplier. The highland mixed farming system directly requires energy for land preparation, cultivation, irrigation, harvesting, post-harvest processing, food production, storage and the transport of agricultural inputs and outputs. However, the most critical shortage impeding the development of the highland system is the lack of household energy. Biomass energy accounts for about one-third of total energy use in developing countries (FAO 2014), but up to 94 per cent of the highland communities rely on biomass for generating household energy for cooking, heating and evening light. Currently only about 2 per cent of the rural population

in the highlands has access to electric energy (Wubalem 2012). The current shortage of energy, combined with an annual population growth rate of about 2.9 per cent, will put additional pressure on fuelwood sources and increase the rate of deforestation and degradation of farmlands. Major fuel deficits are likely to result unless substantial investments are made in the energy sector (ITACADDIS 2014).

Most of the deforestation of highland tropical forests in Angola and Cameroon is due to the need for household energy. The FAO country report indicated that to supply the current demand for woody biomass in Ethiopia, between 150,000 and 200,000 ha of forest cover is lost annually (Wubalem 2012). Biomass consumption in the highlands has exceeded annual forestry yields for decades. As woody vegetation continues to disappear from the vicinity of settlement due to continuous and unsustainable harvest over recent decades, rural households have increasingly switched to cow dung and crop residue as fuel substitutes and for construction materials. A recent study in the central highlands of Ethiopia showed that 92 per cent of the sampled households prioritized the use of animal dung for cooking (in the form of dung cakes) followed by lining for the house (Mekonnen et al. 2011). The estimated annual farm yield reduction due to the diversion of traditional soil fertility management resources, such as crop residue and cow dung, is between 10 and 20 per cent (Barry et al. 2003). On the other hand, *Eucalyptus* planting for construction, fuelwood and as an income-generating commodity is expanding, particularly in the livestock–cereal subsystem where growth of tree options is limited by frost.

Electricity grids in the highlands are expanding, which should have positive effects on agricultural productivity. There is a very high potential for hydropower generation, which is yet to be developed, despite the risks of sediment and silt load. For example, Ethiopia has crafted a comprehensive energy policy prioritizing the expansion, development and utilization of hydropower in its river basins.

Human capital, knowledge sharing and information

Improving agricultural growth and productivity demands the development and promotion of an environment that encourages knowledge to be produced, communicated and applied to a nation's needs (Joint Science Academies statement 2006). The current weak institutional capacity, sectoral policies and fragmented institutional arrangements need to be amended to facilitate knowledge flow and improve communication. This is particularly critical for the remote, mountainous rangelands of the livestock–cereal subsystem, where communication infrastructure is non-existent, local capacity is weak, information flow to end users is at a rudimentary stage and the local governments are not yet mobilized to organize farmers and employ good practices. School enrolment is also very low, prohibiting mutual learning, sharing and utilization of agriculture-related interventions and practices.

However, there have been encouraging developments in recent years. For instance, the Department of Livestock Services in Lesotho has established about 50 livestock improvement centres throughout the mountainous rangelands to provide veterinary services and breeding stock. Similarly, the government in Ethiopia has employed 65,000 agricultural extension agents countrywide to facilitate knowledge flow and provide extension services. There are three agricultural extension agents and one health agent in each kebele (2,000 households). The very recent expansion of mobile phones, including in remote highlands, along with radio services (e.g. farm radio) is expected to revolutionize knowledge flow and market linkages for rural communities across the highland mixed farming system.

System and subsystem performance

Compared to its potential, the highland mixed farming system has large yield gaps relative to other systems in terms of yield per hectare or milk per cow, despite its relatively well-endowed water and land resources. With 70 to 96 per cent of farming in the various countries depending on traditional farming practices and limited inputs, the average crop yield of the highland mixed system is about 1.3 t/ha (Table 8.3) and varies across season. The slight increase in cereal production observed in the highlands in the 2000s was mainly due to expansion of cultivated areas, commonly at the expense of forests. However, area expansion has slowed (in Ethiopia to about 3 per cent per year since 2000) and productivity has been steadily increasing in the 2000s in some countries due to changes in rural infrastructure, expanding urbanization and the adoption of new technologies (Spielman et al. 2011). Crop yield has increased by about 7 per cent per year since 2000 (Tafesse et al. 2012). Annual fertilizer imports in Ethiopia exceeded 950,000 t/year by 2015 (IFDC 2016), mostly applied to cereals, particularly maize and teff, and this is expected to increase given the recent government policies promoting agricultural growth.

There is a substantial difference in productivity among the four subsystems (Table 8.4). In Ethiopia, the low highlands (maize-based subsystem) are relatively high yielding due to their warmer climate, regular rainfall and relatively fertile soils, while the upper, cool livestock–cereal subsystem is less productive due to low temperature, erosion and limited market incentives.

The available information means that productivity can be assessed only through partial productivity measures such as water productivity, labour productivity and nutrient use efficiency.¹ The water productivity of this highland crop–livestock system is very low, with crop water productivity being a bit higher than livestock water productivity. Hailelassie et al. (2009) found that water productivity of crops ranges from USD0.26 to USD0.69 m⁻³ depending on the crop choice, agronomic management and market values. There was no significant difference in crop water productivity between the subsystems although the highland livestock–cereal subsystem had lower crop yield than the highland wheat–pulse and the maize-based subsystems. The water productivity of livestock could be substantially improved in higher altitudes where cereal cropping has low market value. These drivers are forcing farmers to keep livestock at higher densities regardless of feed shortages and high labour demand.

The availability of communal rangelands and the lack of other investment opportunities has encouraged highland farmers to keep a maximum number of livestock even though the resource base may not be able to support productive animals. More than

Table 8.3 Average yield of key cereal and legume species grown in the highland mixed farming system in Ethiopia

<i>Crop species (cereals)</i>	<i>Yield (t/ha)</i>	<i>Crop species (legumes)</i>	<i>Yield (t/ha)</i>
Teff	1.23	Faba beans	1.20
Barley	1.55	Field peas	1.04
Wheat	1.83	Climbing beans	1.49
Maize	2.20	Lentils	1.17

Source: CSA 2010.

Table 8.4 Qualitative comparison of highland mixed subsystems' performance

	<i>Highland livestock-cereal</i>	<i>Highland wheat-pulse</i>	<i>Highland maize-based</i>	<i>Highland mixed North African</i>
Productivity	High livestock productivity but low crop productivity. Low input-low output. Variable potential, constrained by low temperature and poor infrastructure	Medium productivity. Increasing input application, high potential	Medium. Increasing input application, expanding maize. High potential, market-oriented	Low medium productivity of crop, livestock and tree species. Limited access to modern varieties and breeds and external inputs
Sustainability	Mono-crop-dominated. Livestock-based. Limited diversity, fragile	Diversified, high intensification potential. Low risk	Increasing pressure on natural resources. Divers-ified, high intens-ification potential	Intense pressure on natural resources, aggravated by climate change
Human capital	Low, poorly informed	Medium, better access to interventions	Medium, alternative livelihoods available. Better access to interventions, improving capacity	Contrasting strong social capital but low levels of education

90 per cent of farmers in these highlands own only local livestock breeds, although there is significant difference in productivity among breeds. While local poultry breeds lay 55 eggs per year, improved poultry breeds could give up to 150 eggs per year. There is also a huge productivity difference between local zebu (*Bos indicus*), which make up the majority of livestock production, and exotic (*Bos taurus*) or crossbreeds. The milk yield for local dairy breeds is about 2 litres per day, while milk yield for improved cross-breeds is about 9 litres per day with appropriate feed and management. There is also a difference in the length of lactation period between the local and crossbreeds. Low milk productivity and market challenges in this system has affected per capita milk consumption, which is only about 15 litres per capita per year compared to the world average of 115 litres (Spielman et al. 2009). One of the attempts to improve and maintain high yielding breeds under communal grazing in Lesotho involved introducing a national culling and two-for-one animal exchange programme. The livestock feed shortage is another indicator of low productivity; although this varies across seasons and subsystems, the deficit lies in the range of 30 to 45 per cent of the metabolizable energy required for maintenance, growth and productivity. Fortunately, some progress is being made with enclosures of communal catchments and stall feeding of stock.

Nutrient cycling is usually open and nutrient use efficiency low, particularly in the dry highlands (livestock-cereal subsystem), where water stress is apparent and the growing

period is short. The farming in the wet savannah in Cameroon, the mountainous rangelands of Lesotho and the crop-livestock hillsides of Zimbabwe and Ethiopia are areas with poor nutrient cycling due to extremely high soil erosion (up to 100 t/ha soil loss), limited land management practices and low fertilizer inputs. Moreover, there is generally clear soil fertility gradient with decreasing soil nutrient content from homesteads to outfields, which is reflected in crop yields.

The highland mixed farming system also has very low labour productivity due to limited inflow of capital inputs. Typically, 2 ha of land under cultivation may require about 900 hours of labour per year for crop production (Zerbini et al. 1998), mostly family labour. Crop production in Lesotho consumes much more labour than all the other productive activities (Zerbini et al. 1998), despite the importance of the livestock sub-sector. Men are involved in ploughing; women are engaged in weeding, transporting and marketing produce; and children are engaged in livestock rearing. Labour demand differs between rainfed and irrigated farming, and between crop-livestock farmers and crop producers. Perennial crops are considered less labour-intensive while small grain cereals are more labour intensive. For instance in Ethiopia, although teff receives higher returns, teff farming requires much more labour than other crops due to intensive production practices during land preparation, weeding and threshing, requiring about 550 hr/ha (Zerbini et al. 1998). Overall, farm labour shortage is intensifying particularly during harvesting and weeding. Labour shortage is particularly constraining in female-headed households during the peak farming seasons, aggravated by migration of young adults to cities and increasing school enrolment.

Across the subsystems, the current agricultural practices and yield levels do not allow communities to accumulate wealth, due to low saving rates, recurrent droughts, depleting natural resources and declining landholdings. While low system productivity has aggravated rural poverty, lack of capital has also contributed to low productivity of the highland mixed system on multiple fronts. Limited access to reliable markets has reduced farmers' ability to learn about consumer preferences, innovate and adopt and improved practices. Farmers are short of cash to buy basic agricultural inputs, particularly improved breeds, fertilizers, seeds and irrigation equipment. Limited use of these critical inputs has not only affected productivity but also facilitated nutrient mining, deforestation and over-exploitation of resources. Cutting trees for charcoal is a common practice, particularly in areas with good market access. Additional indirect effects of poverty are low access to education and limited knowledge and capacity to respond to emerging climatic and market challenges.

In general, the system is underperforming (Table 8.5) and is waiting for radical policy intervention and diversification of options (Box 8.4).

Table 8.5 Common performance indicators: highland mixed farming system

<i>Variable</i>	<i>Outputs</i>
Average yield / ha for major crops	From 1 t/ha (small grains) to 2.5 t/ha (maize)
Potential yield gap, t/ha	From 2 t/ha (small grains) to 5 t/ha (maize)
Calorie production (crops), kcal/ha	24,600
Protein production (crops), kg/ha	183
Value of production, USD/ha	180–410

Box 8.4 Farm intensification through facilitating organic honey production in livestock-cereal subsystem

The Ethiopian highlands have the potential to produce 500,000 tonnes of honey and 50,000 tonnes of beeswax per annum, but currently production is limited to 43,000 tonnes of honey and 3,000 tonnes of beeswax. There are various initiatives to exploit this potential. For instance, communities in the mountainous and challenging terrains of the livestock-cereal subsystem have been engaged in beekeeping as an additional source of income since 2003. Farmers were encouraged to introduce beehives individually or collectively in the landscapes including in exclosures (negotiated land protected from livestock and people to assist recovery) as incentives to protect the landscapes. Two NGOs, SoS Sahel and Oxfam UK, set out to help these communities to modernize traditional beekeeping practices and transform small-scale, low value production into a model of commercialized beekeeping. They have helped to create the Zembaba Farmers Union, which has helped to increase honey productivity by up to 400 per cent and to boost incomes by 200 to 400 per cent. Increased incomes have enabled smallholders to invest in education and other services. The NGOs are trying to scale out these experiences to 40,000 beekeepers.

Source: Oxfam UK, 2011.

Strategic priorities for the system

The highland mixed system shares common social, ecological and economic challenges. These include weak local institutions to respond to climatic and market shocks, limited human capital in the farming sector, limited agribusiness opportunities to add value to agricultural produce, high population density and growth, severe soil erosion, farm fragmentation, declining land holding per capita, high soil nutrient imbalance, declining soil fertility, overstocking and poor market infrastructure. Strategies of households in the SSA parts of the highland mixed farming system for improving their livelihoods are reported in Table 8.6, and some key priorities for the system are outlined later. The portfolio of strategies has evolved from 2000 to 2015, notably with increased opportunities for intensification of the system and reduced opportunities, overall, for diversification (relative to other strategies for improved livelihoods). While exit from agriculture remains the most important strategy to improve livelihoods for both groups, the better off households have greater prospects for increased farm or herd size and, notably, increased off-farm income than extremely poor households. The portfolio of highland mixed North African subsystem poverty escape pathways are similar to those of the SSA subsystems presented in Table 8.6 except that intensification and increased farm size are of minimal importance and off-farm income and exit are of greater importance.

Market infrastructure

The highland mixed farming system is characterized by undercapitalization of market infrastructure, high transaction costs and low market linkages. Improved road infrastructure would increase market participation, enable the formation of market cooperatives,

Table 8.6 Relative importance of household livelihood improvement strategies

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total ag pop	—	55	45	100
Intensification	1	3	2	2.5
Diversification	3	2	1	1.5
Increased farm size	2	1	2	1.5
Off-farm income	1	1	2	1.5
Exit from agriculture	3	3	3	3

Sources: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

Note: refers to the SSA part of the highland mixed system.

increase market volume and improve negotiation capacity of communities in selling their goods and services. If smallholders can gain some of the value currently captured by middlemen, then their commercial equation changes (Grow Africa 2014). Providing rural credit for farmers would also help to improve the productivity and marketing of produce at the time of their choice, particularly by linking producers and processors. The expansion of mobile phone connectivity and radio stations to isolated highland communities would also create local capacity, facilitate input–output markets and link farmers to diverse livelihood opportunities, including off-farm jobs. In general, pro-poor policies and public investments in infrastructure will be essential to create incentives, reduce transaction costs and improve risk management (Herrero and Thornton 2011).

Mountain niche product diversification

Specific mountain products and services including mountain tourism, medicinals, highland fruits, flowers, honey and other organic food items are in increasing global demand (ICIMOD 2011). Highland farmers could effectively compete in national and international markets if they are able to exploit their distinct agroecology and traditions by producing superior quality products with certified food origins that meet sanitary requirements and other policies of niche markets. In fact, the highland mixed system may have a comparative or exclusive advantage in niche markets (ICIMOD 2011) because of its cool climate, predominantly low input agriculture and relatively cheap labour. For instance, white organic honey from the highlands of Ethiopia is now reaching European markets. Highland roses have been an emerging sector in the last ten years, particularly in the wheat–pulse subsystem and livestock–cereal subsystem, with increasing demand in global markets. For example, on Valentine's Day in 2013, 70 per cent of the roses sold in France came from the Ethiopian highlands (*The Reporter* 2013). There is also increasing recognition of mountain ecosystem services in regulating regional and national freshwater supplies with potential markets through green marketing, benefit-sharing mechanisms, ecotourism and other services.

Farming system intensification

This is a low-input low-output system but has very high potential for intensification. In general, the use of inputs is increasing. Given the low crop and livestock yields (Tables 8.3 and 8.5), far below the potential, there is an opportunity to improve productivity. Productivity gains could be made in the more extensive mixed rainfed areas with targeted

intensification and risk reduction technologies for reducing the impacts of climate variability (Herrero and Thornton 2011). Intensification encompasses increased physical or financial productivity of existing patterns of production, including food and cash crops, livestock and other productive activities through greater use of external inputs. It may also arise from improved varieties and breeds, utilization of unused resources, improved labour productivity and better farm management (Dixon et al. 2001). The risk reduction interventions may include more watering points for livestock drinking, reforestation of hillsides and water towers, and protection of valley bottoms and wetlands. There is a need to ensure continued improvement in productivity by promoting targeted application of external inputs, in particular seeds, fertilizers and irrigation. With appropriate policy and technological innovations, land scarcity could give rise to adaptation and dynamic changes in farming and broader socioeconomic systems (Jayne et al. 2014). For instance, transforming the extensive wool and mohair production of the highland mixed farming system by improving rangeland management, feed availability, fibre quality, and veterinary and marketing services would substantially increase farm income in Lesotho, while improving the resilience of this system. Sustainable intensification could increase productivity per unit area and enable the system to increase and potentially enhance food security and create agricultural job opportunity.

If properly integrated into this traditional highland mixed farming system, biotechnology applications could make a difference in improving food security and resilience. Agricultural biotechnology encompasses a variety of innovative methods including clonal propagation of disease-free plants, gene identification and isolation for addressing specific stress factors, genetic engineering for traits such as pest and disease resistance, better adaptation to environmental stresses, greater nutritive value and reduced post-harvest losses, and genetically engineered male sterility to facilitate hybrid seed production (Kelemu et al. 2003). For instance, soil acidity and the associated phosphorus fixation are some of the major production constraints in the maize-based subsystem. Developing acidity tolerant crop varieties or injecting phosphorus-solubilizing bacteria using biotechnology could transform the system. Potato production is currently suffering from late blight (*Phytophthora infestans*) in the livestock-barley subsystem, and propagation of clean seed using biotechnology is urgently needed. Naturally, use of biotechnology should conform to bioethics principles, national regulations and biotechnology monitoring mechanisms.

Market-oriented livestock production

The system has a huge potential for commercial livestock production, if the critical constraints of feed shortage, livestock diseases, low productive breeds and market failure are corrected. The rapid growth in demand for meat and milk products globally offers significant opportunities for the highland mixed farming system. In particular, the Middle East markets offer a huge opportunity to increase productivity and income by satisfying sanitary and phytosanitary standards, and quality and quantity preferences of importing countries. However, the highland mixed system currently lacks a quality grading system that would reward quality and promote market transparency – this would need to be developed.

Investment in natural resources and climate change adaptation

Improved resource management is a strategic investment to improve functionality of the highland mixed system, and is consistent with Pillar I of CAADP (see earlier section).

Since the 1960s the governments in Lesotho and Ethiopia have realized the need to reverse land degradation and improve natural resource management.

Landscape management cannot be sustainable unless it brings economic and livelihood benefits to the local people. This can best be done by promoting sustainable intensification of the highland mixed crop-livestock farming system, which requires functional interactions among multiple-components, including the natural resource base, human capital, socioeconomic realities and the innovations required to sustainably use the resources while maintaining the resource base for future generations.

A key issue that determines the success of natural resource management/sustainable land management is how it is implemented and how well communities are involved. There have been multiple attempts at reforestation, although success has only been seen in a few localities. The early successes were those supported by strong local government, with facilitation supported by external donors, and strong commitment and collective action by communities to get out of despair and poverty. In other cases, natural resource management has failed to be adopted by rangeland communities due to weak enforcement mechanisms, as was the case with the Basotho chiefs of Lesotho. The policy priority across the highland mixed system should be scaling out these localized success stories regardless of external support (Amede 2014).

The ongoing initiatives in sustainable land management, particularly through soil and water conservation structures and exclosure of degraded landscapes, should be institutionalized across the highland mixed system. The current resource degradation and future climate adaptation in the highlands could be best addressed through employing rainwater management strategies at landscape scales. Rainwater management is an integrated strategy that enables communities to systematically map, capture, store and efficiently use runoff and surface water emerging from farms and watersheds in a sustainable way for productive and domestic purposes and for ecosystem services (Amede et al. 2011). Integrated rainwater management aims to decrease unproductive water losses (runoff, evaporation, conveyance losses, deep percolation) from a system, as well as increase the water productivity of the respective enterprises to increase returns per unit of water investment. This approach is complementary to what governments in the respective countries have been promoting in the highland mixed system.

Despite the local successes and increasing investment in sustainable land management to improve the highland range management, the initiatives were largely unsuccessful, often due to inappropriate coercive and regulatory approaches. For example, the land management policies are commonly non-participatory, the implementing institutions lack human and organizational capacity, and incentives for communities for these long-term investments are non-existent. The few successful ones, as in the Ethiopian highlands and in Rwanda, are those which have strong central government enforcement strategies along with incentive mechanisms. For instance, in the Tigray regional state, northern Ethiopian highlands, where land degradation and recurrent drought were a major challenge, the system has been largely rehabilitated through improved watershed management, particularly construction of terraces and water harvesting structures, introducing enclosures to rehabilitate degraded landscapes and exclude livestock and people, and strengthening local bylaws. The effect is now visible as the vegetation cover has increased by about 10 per cent, erosion effects are reduced and new springs are emerging. The regional Bureau of Agriculture reported that food grain production increased five-fold during the period 1993 to 2011 (pers. comm. Belete, 2012).

Alternative energy sources

Modernizing energy inputs to agriculture has been an essential feature of agricultural development in developed economies. Similarly, higher inputs of modern energy into the highland system would have a positive impact on agricultural and labour productivity. For the system to function sustainably, there is a need to promote alternative energy sources, particularly increasing connectivity to the electric grid. Energy saving stoves are gaining prominence, but are awaiting wide-scale dissemination. The mountainous highlands have an enormous potential for hydropower development, which is gaining global attention in response to increasing energy demand and climate change. Localized rural electrification through wind (a lot of it in the highlands!) and solar energy is also expected to trigger change. Such initiatives would allow the dung currently used for cooking to be used for soil fertility management and/or generation of energy (methane), which would also help to minimize the negative effects of livestock on climate change.

Energy policy measures, if properly implemented, could reduce deforestation, return manure to soil fertility improvement, facilitate sustainable intensification of the farming system, create off-farm opportunities and reduce pressure on the natural resources base. Infrastructure to generate energy should be supplemented by increasing afforestation of the hillsides, gullies, river banks and degraded landscapes using best agroforestry practices, to increase farm-level biomass production and afforestation. If more land is planted and dedicated to energy crops, farming might make important contributions to reducing national energy costs and greenhouse gas emissions. This should be implemented through proper land use planning without compromising food security and environmental services.

Strengthened policy and institutional environment

Intermittent policies along with shifting roles of the public and private sectors may have been a disincentive for creating expected benefits and impacts. Subsidies could facilitate farmer innovation and willingness to risk trying new technologies and practices, thus allowing farmers to learn about inputs, and to develop market opportunities and integrate subsistence farmers with bigger market transactions. Agricultural transformation in Asia and Europe happened due to decades of subsidies to farmers, and it is regrettable that African countries were advised to abolish these programmes. Subsidies should be reintroduced to trigger change and give a strong push to agriculture.

Increased and targeted use of inputs, particularly fertilizer blends, will help reduce deforestation and incursion by farmers onto protected areas, wetlands and hillsides by enabling them to produce more with the existing farm lands. There are good experiences in Malawi, where farmers significantly increased production using fertilizer subsidies. However, there is also a need to establish an exit strategy for farmers given the potential for increasing costs once farmers are convinced to use more inputs and the risk of dependency on the state.

Limited access to credit could also leave small farmers in a poverty trap from which they struggle to escape, even when the technology exists to allow them to produce more. For instance the Lesotho Agricultural Development Bank has played a very important role in facilitating adoption of livestock technologies. But the bank has been on the verge of collapse due to fading policy support (FAO 2005). Microfinance schemes have been expanding, but the very high interest rate is repelling farmers from taking credit unless

reliable markets are assured. Crop and livestock insurance is also another promising strategy showing positive results in pilot sites.

With the current scenario of increasing population and decreasing farm size, most farmers are in search of off-farm jobs that enable them to accumulate capital and, with time, exit out of agriculture to move to rural towns and urban centres. Increased use of inputs could have multiple effects in reducing hunger and poverty including through creating the financial capacity to invest on non-farm income-generating activities (Table 8.6).

Policy support for small-scale commercial and mechanized farming

Large-scale investment in land has been limited due to policy distortions against agriculture (Deininger and Byerlee 2011). This has reduced exports and public investment in rural areas and limited agricultural development in the continent. There is a need to eliminate many of these policy interventions to accelerate and renew investor interest in the continent (Deininger and Byerlee 2011). However, social tension could result from a lack of alternative livelihoods for those excluded from commercial and mechanized farming, and the social tension is likely to outweigh investment benefits, unless supporting policies are developed for exit or smallholder farming.

Land use and land rights policy

There is a need for land tenure policies to ensure equitable access to farmland and provide incentives for smallholder investment in their farms. Land rights policy varies by country, with Cameroon having absolute and exclusive private property rights, while Mozambique and Lesotho practise customary community land rights, and in Ethiopia land is public property. The various tenure regimes have differing implications for agricultural development.

There is also a need for policies to manage uncontrolled communal grazing. The free movement of animals (e.g. Lesotho) is a disincentive for improved landscape management – preventing farmers from on-farm tree planting, maintenance of soil-water conservation structures, and practising conservation agriculture through leaving crop residues on the ground. Rangeland degradation due to uncontrolled communal grazing is a major threat to livelihoods in Lesotho. Despite the submission of policy recommendations, there is not yet an enforced national land use policy in these countries. However, some communities have developed their own local bylaws that prohibit livestock movement during the growing seasons and around irrigable areas during the dry season. Depending on the frequency and severity of the effect of incursion of livestock into the private and protected farms and grasslands, there are social and financial penalties.

A policy challenge in some countries is foreign investment through resettlement of communities to less populated areas through ‘negotiated goodwill’. Foreign investment in commercial agriculture has been creating job opportunities for farmers, particularly in countries where the legal and regulatory framework for large-scale land acquisition is enforced. In some instances off-farm income from foreign investments has enabled farmers to buy the required agricultural inputs and improve their livelihoods.

Strengthening research capacity

African countries must be able to develop, adapt and exploit scientific and technological solutions appropriate to their specific needs. The countries should recognize that

investment in a country's own science capabilities, along with development of merit-based processes and institutions, is essential to the successful utilization of science, technology and innovation in Africa for solving current and emerging challenges, and is fundamental to sound policy making, good governance and development (Joint Science Academies Statement 2006).

Aside from budgetary constraints, many African public research organizations face serious institutional constraints that inhibit their effectiveness and ability to attract funds, and ultimately prevent them from functioning as a major contributor to the innovation system (World Bank 2012). There have been limited attempts to solve the major constraints of ever changing strategic visions, ineffective leadership and management, loss of highly qualified scientific staff, and weak links with, and accountability to, other research and development actors in the respective countries (World Bank 2006).

At the Second Ordinary Assembly of the African Union in July 2003 in Maputo, African Heads of State and Government endorsed the Maputo Declaration on Agriculture and Food Security in Africa and agreed to commit to "the allocation of at least 10 percent of national budgetary resources to agriculture and rural development policy implementation within five years". However, very few countries are delivering their commitments. There is a need for increased investment in building research infrastructure and in human resources in key innovation areas, such as biotechnology and climate science.

Diversifying livelihood options for poverty reduction

The highland communities are predominantly agrarian operating under unpredictable climatic conditions but with limited alternative income sources. Increased investment in processing of agricultural produce would create job opportunities and contribute to value addition. One of the livelihood strategies that rural communities in the highland mixed system have been adopting in recent years is out-migration in search of rural off-farm employment (e.g. sugar estates, coffee, sesame and cotton growing areas), and to larger towns particularly the construction sector, and increasingly to the Middle East and Gulf states. In 2010, the estimated number of migrants from Ethiopia was 620,000, and for Lesotho it was about 427,000, with an incoming remittance of USD1.5 billion and USD425 million per year, respectively. The flow of the larger part of this remittance into rural communities is supporting the purchase of agricultural inputs, paying school fees, health services and other household needs. Temporary migration, if supported with proper policies, could increase information and knowledge flow, regularly inject much-needed cash into the rural economy and facilitate overall system change.

System conclusions

The highland mixed farming system contains very fragile ecosystems, where rural poverty is high and about 37 per cent of the population lives on a daily income of less than \$1.25USD per day. The mountainous areas are usually far away from government power and receive limited policy attention. Besides climate change risks, the system is prone to water erosion. Deforestation has been a major cause of resource degradation, reduced crop and livestock productivity, and reduced water yields. On the other hand, this system has high potential, with high rainfall, a favourable climate, distinct biodiversity and opportunities for green energy. A well-managed highland system would benefit downstream communities and beyond: economic growth and sustainability of downstream systems depend hugely on resources coming from the mountains.

Green growth is feasible in the highland mixed farming system: multiple water uses including hydropower generation and tourism could be developed and efficiently utilized. It calls for strong institutional support, where individuals and organizations with facilitation and/or brokering skills can help households to pool their limited resources among themselves or with other actors to achieve economies of scale, enter new markets, or access new resources such as technical information or credit (World Bank 2006). Organizations could help by fostering economic growth, creating employment, preventing buyers from benefiting at the expense of suppliers, building innovation capabilities and protecting marginal groups (such as women or landless farmers) from further marginalization (World Bank 2012).

In conclusion, this system needs particular policy attention and investment in the following areas:

- improvement in cooperation between upstream and downstream communities to boost the management of fragile upstream landscapes, including payments to the communities of the highland mixed farming system for ecosystem services from sustainable management of the highlands
- sustainable investment in communications, road and market infrastructure to integrate the highland farming system into urban, national and regional markets with an emphasis on diversification into niche mountain products
- ensuring that highland mixed system communities benefit from climate change conventions and climate financing mechanisms
- investment in rural energy that improves the farming system productivity, through natural resource management, information and market connectivity, household management and educational opportunities
- building the organizational and brokering skills of highland communities to manage their limited resources or to attract new resources, achieve economies of scale, enter and compete in new markets, and ultimately improve their livelihoods
- ensuring implementation of jointly developed strategic research, through creating an enabling environment for effective leadership of participatory and transdisciplinary research, retention of highly experienced scientific staff, fostering innovation at the research-extension interface and sharing knowledge across research and development actors in different countries with the highland mixed farming system.

Note

- 1 The productivity of this farming system would be best measured through total factor productivity (TFP), which is a ratio of total outputs to total inputs (measured in an index form). If the ratio of total outputs to total inputs is increasing, then the ratio can be interpreted to mean that more outputs can be obtained for a given input level (Ehui and Jabbar 2002).

References

- Abera, D. 2010. *Accelerated Growth in Ethiopian Agriculture*. Ministry of Agriculture and Rural Development. Addis Ababa, Ethiopia.
- Ali, S.N. 2007. *Climate Change and Economic Growth in a Rain-Fed Economy: How Much Does Rainfall Variability Cost Ethiopia?* Ethiopian Economic Association. Ethiopian Economic Association Working paper series, Addis Ababa, Ethiopia.

- Amede, T. (ed.) 2003. Natural resource degradation and environmental concerns in the Amhara National Regional State: Impact of food security. Proceedings of the Natural Resource Management Conference, Bahir Dar, Ethiopia, 24–26 July 2002. Ethiopian Soil Science Society, pp. 185–207.
- Amede, T. 2014. Technical and institutional attributes constraining the performance of small-scale irrigation in Ethiopia. *Water Resources and Rural Development* 6: 78–91.
- Amede, T., Tarawali, S. and Peden D. (eds). 2011. Improving water productivity in crop livestock systems in drought prone regions. Special Issue, *Experimental Agriculture* 47(1). Cambridge University Press.
- Argaw, A. 2012. Highlands vulnerability to climate borne diseases. *A Paper Presented at the National Workshop on Climate Resilient Highland Transformation*, Tigray National Regional State Science and Technology Agency, 21–23 June, Mekelle, Ethiopia.
- Barry, L., Olson, J. and Campell, D. 2003. *Assessing the Cost and Impact of Land Degradation at the National Level: Overview, Findings and Lessons Learned*. www.global-mechanism.org/dynamic/documents/document_file/cost-of-land-degradation-case-studies.pdf.
- Bureau of Statistics. 2013. *Lesotho Livestock Products*. Statistical Report No. 13. Kingdom of Lesotho.
- Chamberlin, J. and Schmidt, E. 2011. *Ethiopian Agriculture: A Dynamic Geography Perspective*. Ethiopia strategy support programme II. ESSPII, Working paper No. 017, March 2011. IFPRI.
- CSA (Central Statistical Agency). 2010. *Report on Area and Production of Crops: Agricultural Sample Survey, Volume IV*. Statistical Bulletin 446, Addis Ababa, Ethiopia.
- Degrande, A., Schreckenber, K., Mboosso, C. and Mfoumou, C. 2007. *Farmer Livelihoods in the Humid Forest and Moist Savannah Zones of Cameroon*. Working Paper nr 47 . Yaoundé, ICRAF-WCA/HT.
- Deininger, K. and Byerlee, D. 2011. *Rising Global Interest in Farmland. Can It Yield Sustainable and Equitable Benefits*. The World Bank.
- Dixie, G. and Jayaraman, N. 2011. *Strengthening Agricultural Marketing with ICT*. World Bank. www.ictinagriculture.org/sites/ictinagriculture.org/files/final_Module9.pdf.
- Dixon, J., Gulliver, A. and Gibbon, D. 2001. *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World*. FAO and World Bank.
- Ehui, S. and Jabbar, M. 2002. *Measuring Productivity in African Agriculture: A Survey of Applications of the Superlative Index Numbers Approach*. Socio-economics and policy research working paper 38. International Livestock Research Institute (ILRI).
- Ethiopian Economic Association. 2000. *Annual Report on the Ethiopian Economy Vol. I, 1999–2000*. www.eaecon.org/node/5500.
- FAO. 2005. *Livestock Sector Brief, Lesotho*. FAO and livestock information sector analysis and policy branch, AGAL. March 2005, Rome.
- FAO. 2014. Website. www.fao.org/docrep/004/ab582e/AB582E03.htm.
- FAOSTAT (undated) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- GCCA (Global Climate Change Alliance). 2014. Website. www.gcca.eu/national-programmes/africa/gcca-lesotho.
- Gockowski, J., Tonyé, J., Diaw, C., Hauser, S., Kotto-Same, J. and Njomgang, R. 2005. The forest margins of Cameroon. In Palm, C., Vosti, S., Sanchez, P. and Ericksen, P. (eds) *Slash-and-Burn Agriculture: The Search for Alternatives*. Colombia University, pp. 305–331.
- Grow Africa. 2014. *Agricultural Partnerships Take Root Across Africa. Second Annual Report on Private Sector Investment in Support of Country-Led Transformations in African Agriculture*. www3.weforum.org/docs/IP/2014/GA/WEF_GrowAfrica_AnnualReport2014.pdf.
- Haileslassie, A., Peden, D., Gebreselassie, S., Amede, T. and Descheemaeker, K. 2009. Livestock water productivity in mixed crop-livestock farming systems of the Blue Nile Basin: Assessing variability and prospects for improvement. *Agricultural Systems* 102(1–3): 33–40.
- Hazell, P. and Wood, S. 2008. Drivers of change in the global agriculture. *Philosophical Transactions of the Royal Society* 363: 495–515.

- Herrero, M. and Thornton, P.K. 2011. *Production Systems for the Future: Balancing Trade-Offs between Food Production, Efficiency, Livelihoods and the Environment*. A key note paper. http://aci-ar.gov.au/files/node/13987/keynote_3_19864.pdf.
- Holden, S.T., Deininger, K. and Gebru, H. 2011. Tenure insecurity, gender, low-cost land certification and land rental market participation in Ethiopia. *Journal of Development Studies* 47(1): 31–47.
- ICIMOD. 2011. *Value Chains for Mountain Products and Services*. Information sheet No. 3/11. International Centre for Integrated Mountain Development. Kathmandu, Nepal.
- IFDC. 2016. Fertilizer Statistics Overview: Ethiopia, 2012–2015. africafertilizer.org/wp-content/uploads/2017/05/Ethiopia-Fertilizer-Statistics-Overview-2015.pdf.
- IGAD. 2010. *The Contribution of Livestock to the Economies of IGAD Member States*. IGAD LPI working paper No 02–10.
- ITACADDIS (Italian Development Cooperation). 2014. Website. <http://www.itacaddis.org/italy/index.cfm?>
- Jayne, T.S., Chamberlin, J. and Headey, D. 2014. Land pressures, the evolution of farming systems, and development strategies in Africa: A synthesis. *Food Policy* 48: 1–17.
- Joint Science Academies Statement. 2006. *Science and Technology for Development in Africa*. www.interacademies.net/File.aspx?id=6431.
- Kelemu, S., Mahuku, G., Fregene, M., Pachico, D., Johnson, N., Calvert, L., Rao, I., Buruchara, R., Amede, T., Kimani, P., Kirkby, R., Kaaria, S. and Ampofo, K. 2003. Harmonizing the agricultural biotechnology debate for the benefits of African farmers. *African Journal Biotechnology* 2(11): 394–416. Special Anniversary Review.
- Mekonnen, S., Descheemaeker, K., Tolera, A. and Amede, T. 2011. Livestock water productivity in a water stressed environment in Northern Ethiopia. *Experimental Agriculture* 47(1): 85–98.
- Negassa, A., Rashi, S. and Gebremedhin, B. 2011. *Livestock Production and Marketing*. IFPRI ESSPII Working paper 26. Addis Ababa, Ethiopia.
- NEPAD. 2009. *How are Countries Measuring up to the Maputo Declaration?* Policy brief, June 2009. www.nepad-caadp.net/pdf/How%20are%20countries%20measuring%20up%20to%20the%20Maputo%20declaration.pdf.
- New Agriculturist*. 2001. Cameroon, Country profile. www.new-ag.info/en/country/profile.php?a=871.
- Nomathemba, M. 2010. *Private Sector Agribusiness Investment in Sub-Saharan Africa. Agricultural Management, Marketing and Finance*. Working Document 27. FAO.
- Oxfam UK. 2011. Engaging smallholders in value chains. *Program Insight*.
- Shiferaw, A., Soderbom, M., Siba, E. and Alemu, G. 2012. *Road Networks and Enterprise Performance in Ethiopia. Evidence from the Road Sector Development Programme*. International Growth Centre (IGC), Working paper 12/0696. www.theigc.org/sites/default/files/Road%20networks%20and%20firm%20performance_Adamasu%20Shiferaw%20et%20al_2012.pdf
- Shiferaw, B., Jaleta, M., Kassie, M. and Yirga, C. 2013. Adoption and impact of improved maize and wheat varieties in Ethiopia: Empirical evidence. *Invited paper presented at the Third Dialogue on Ethiopian Agriculture*, 4–5 July 2013, Haramaya University, Ethiopia.
- Smaling, E.M., Nandwa, S. and Jenssen, B. 1997. Soil fertility in Africa at stake. In Buresh, R., Sanchez, P. and Cahoun, F. (eds) *Replenishing Soil Fertility in Africa*. SSSA special publication number 51, pp. 47–62.
- Spielman, D., Kelemework, D. and Alemu, D. 2009. Policies to promote smallholder intensification in Ethiopia. The search for appropriate public and private roles. IFPRI (unpublished).
- Spielman, D., Kelemework, D. and Alemu, D. 2011. *Seed, Fertilizer, and Agricultural Extension in Ethiopia. Ethiopia Strategy Support Programme II (ESSP II)*. ESSP II working paper 20. International Food Policy Research Institute (IFPRI) and Ethiopian Development Research Institute (EDRI).
- Tafesse, A.S., Dorosh, P. and Asrat, S. 2012. *Crop Production in Ethiopia: Regional Patterns and Trends. Ethiopia Strategy Support Programme (ESSP-II)*. Research Note 11. IFPRI.

- The Economist*. 2014. African population: Can it survive such speedy growth? 23 August.
- The Reporter*. 2013. Roses from Ethiopia: A booming market. www.thereporterethiopia.com/index.php/living-and-the-arts/lifestyle/item/241-roses-from-ethiopia-a-booming-market.
- UNCSD (The United Nations Conference on Sustainable Development). 2012. www.unscd2012.org/content/documents/287.
- World Bank. 2006. *Agriculture Investment Sourcebook*.
- World Bank. 2012. *Agriculture Innovation Systems. An Investment Sourcebook*.
- Wubalem, T. 2012. The status of forestry development in Ethiopia: Challenges and opportunities. *A Paper Presented at National Dialog on Sustainable Agricultural Intensification in Ethiopia and its Role on the Climate Resilient Green Economy Initiative in Ethiopia*. 23–24 July 2012, ILRI Campus, Addis Ababa, Ethiopia.
- Zerbini, E., Shapiro, B. and Chirgwin, J.C. (eds). 1998. Technology transfer: Multi-purpose cows for milk, meat and traction in smallholder farming systems. *Proceedings of Expert Consultation, ILRI, Addis Ababa, Ethiopia*, 11–14 September 1995. ILRI (International Livestock Research Institute), Nairobi, Kenya.

9 The tree crop farming system

Stagnation, innovation and forest degradation

Jim Gockowski

Key messages

- To raise the income of the existing cocoa and oil palm smallholder farming system will require the adoption of improved varieties and fertilizers by farmers. Sustainably intensifying the existing tree crop farming system will require major private investment in fertilizer marketing capacity and rural banking along with public policies supporting growth of the private sector and public sector research on tree genetics and agronomy.
- In relatively land abundant regions, large-scale foreign investment can offer immediate access to improved tree crop technology capable of employing thousands of workers and growers while generating taxable revenue bases for government investment in fundamental public goods such as education and health. However, the threat of land alienation requires significant negotiation and dialogue with local community organizations and institutions.
- Contractual out-grower arrangements between the industrial plantation system and local communities have proven widely successful in reducing poverty and assuaging land alienation among smallholders. In the oil palm sector of South East Asia smallholder production using industrial plantation technology is encouraged and accounts for roughly one-third of South East Asian output. Out-grower schemes have been tested successfully in parts of west Africa and should be scaled out.
- Without investment in sustainable intensification there is little hope of conserving the remaining forest remnants in west Africa; at the same time poverty will not be easily vanquished in the Congo basin without some trading of the environment given the extremely limited production and trade possibilities for this region of the world. New institutions such as the Roundtable on Sustainable Palm Oil are helping to minimize these trade-offs.

Summary

The tree crop farming system in Africa is distinguished from other farming systems by a greater reliance on global markets. While suited to most of the humid lowlands of west and central Africa, the competitive pressures of global markets effectively limit the tree crop farming system to west Africa where relatively efficient marketing systems link tree crop producers to those markets. Three principal tree crop farming subsystems have

been identified. The two smallholder subsystems are distinguished by their management of plant nutrients; the forest rent subsystem (FRS) relies on the inherent stock of plant nutrients in both the soil and forest biomass, whereas the smallholder intensified subsystem (SIS) maintains nutrient balances through the addition of external inputs such as mineral fertilizers, organic fertilizer or animal manures. The third subsystem is the large-scale industrial plantation subsystem (IPS), which is heavily capitalized and much more focused on profit than the typical smallholder system. The two main smallholder tree crops are cocoa and oil palm, with robusta coffee, citrus and rubber of secondary importance. The industrial plantation is mainly focused on the production and processing of rubber and oil palm.

The FRS is by far the most widespread in terms of area, output and number of households engaged. The term 'forest rent' refers to the subsystem's reliance on the nutrients tied up in the forest biomass, which underlie the productivity of this system. Forest rents are finite and depreciate over time as plant nutrients are exported out of the system in the form of commodity exports to global markets. Ultimately, nutrient depletion leads to declining productivity causing some farmers to switch to less nutrient-demanding crops such as oil palm and rubber, or transitioning to a commercially oriented root and tuber crop farming system, when there is access to rapidly growing urban food markets. Historically another option was to abandon the field and seek out new forest for conversion. In much of west Africa this is no longer possible due to demographic pressure.

The SIS is extremely limited in extent for various reasons, paramount of which is the limited development of the private sector and a general lack of affordable fertilizer supply. Limited port capacity and poor road infrastructure often mean that fertilizer markets are unable to capture economies of scale in transport and blending. This raises fertilizer costs at the farm gate, increases the financial risk associated with their use and prevents many smallholders from participating in the fertilizer market. Higher variable costs associated with the intensified system can also be a strain for financially strapped smallholders. Developing financial systems that can provide short-term credit for purchasing inputs will be critical. The environmental costs of not evolving towards more intensified subsystems include those associated with potentially irreversible nutrient depletion as well as forest degradation and deforestation.

Poverty in tree crop farming communities is largely a function of the household's productive assets. The most vulnerable are sharecroppers, whose assets mostly consist of unskilled labour. Their income is highly variable depending on commodity prices and the productivity of the land sharecropped. Demographically, many are socially isolated migrant workers with little if any formal education. To generate the employment needed to address this hotspot of poverty, greater investment in the labour intensive IPS is recommended. The increased demand for unskilled agricultural labour would lead to higher wage rates and reduced poverty.

Description of the tree crop farming system

The tree crop farming system has been an important component of west and central African farming since ancient times. Evidence from palm oil residues found in an Egyptian tomb, Abydos, strongly suggests that oil palm was cultivated over 5,000 years ago in west Africa. More recently, Tetteh Quarshie, a Ghanaian blacksmith and farmer, was a principal figure in the establishment of the cocoa industry in the late 19th century. After several years working on cocoa farms in Fernando Po, Tetteh returned to his village in

eastern Ghana and made the first commercial planting of cocoa on the African continent in 1879 (Simpson 1937). An ensuing land scramble was described “where land became a factor which was quantified and bought then sold on commercial terms” (Hill 1963). The founding fathers of the west African cocoa industry were groups of capitalist entrepreneurs from Akwampim in eastern Ghana that organized group purchases of largely uninhabited forest land for cocoa production.

These companies which were basically groups of friends (not relatives) from one home town, were land purchasing clubs which enabled rich and poor alike to buy land for cocoa growing, each member being allotted a strip of land of a width proportionate to the sum he proposed to contribute.

(Hill 1963)

Figure 9.1 Location of the tree crop farming system in Africa.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Enthusiasm for cocoa production continued to grow and by 1911 Ghana had become the world's largest cocoa producer. West Africa, now led by Côte d'Ivoire, maintains its dominance in the market, accounting for 73 per cent of global production over the last few seasons (ICCO 2015).

Approximately 82 million Africans live within the estimated boundaries of the tree crop farming system (Figure 9.1, Table 9.1). A large majority (88 per cent) live in west African countries with the remainder in Madagascar (7 per cent) and Cameroon (5 per cent) (Table 9.2). The rural population within the boundaries of the farming system is currently increasing by 1.2 per cent annually and will double by 2075 at this rate. The current average population density is 66 rural inhabitants per km².

Crop production is focused on cocoa, oil palm, rubber, robusta coffee and citrus, which are all traded on international markets. Palm oil produced in west Africa is primarily for the west African market. In Madagascar, the principal tree crops produced are robusta coffee and cloves.

The feasible growing region for the principal tree crops includes most of the Congo basin and the Guinea forest of west Africa. However, high marketing costs in Central Africa prevent producer access to global commodity markets, effectively limiting the tree crop farming system to those regions where market access is high (Table 9.1).

Animal production in the humid lowlands of west and central Africa is generally very extensive and has only slight interaction with the tree crop farming system. Animal production is free-range and mainly restricted to dwarf goats, sheep, pigs, fish and chickens. Cattle are scarcely present due to the presence of trypanosomiasis. Animals are slaughtered most typically on important social occasions and are rarely taken to market except in times of financial need. They are also typically exchanged in marriage arrangements. On the production side, animal manure is important as fertilizer input for tree crop farming when the tree crop farm is adjacent to the household compound. However, manure quantities are generally quite limited.

Table 9.1 Basic system data (2015): tree crop farming system

<i>Item</i>	<i>Data</i>
Total human population (million)	82
Agricultural population (million)	30
Total area (million ha)	64
Cultivated area (million ha; % of total area)	7.6; 12
Irrigated area (million ha; % of cultivated area)	0.1; 2
Total livestock population (million TLU)	3
Major agroecological zone	Tropical warm humid
Length of growing period (average, days; core range, days)	299; 270–330
Access to services (low/medium/high)	High
Distance to 50k market (average, hr; core range, hr)	4.7; 1–6
Agricultural population density (persons/total area; persons/cultivated area)	0.5; 3.9
Livestock density (TLU/total area; TLU/cultivated area)	0.05; 0.4
Standard farm and herd size (cultivated area/household; TLU/household)	1.4; 0.6
Extreme poverty (% of rural population)	40

Source: Refer to Table 2.4.

Table 9.2 Urban and rural population size, population growth rates and rural density estimates in the tree crop farming system regions

	<i>Population 2015</i>		<i>Growth rate 2000–2015</i>			<i>Rural density</i>
	<i>Urban</i>	<i>Rural</i>	<i>Urban</i>	<i>Rural</i>	<i>Total</i>	<i>Persons/km</i>
	<i>M</i>	<i>M</i>	<i>%</i>	<i>%</i>	<i>%</i>	
Cameroon	3.5	2.9	3.7	1.4	2.6	23
Côte d'Ivoire	8.4	7.1	3.3	0.4	1.8	44
Ghana	5.4	4.6	3.8	1.1	2.4	73
Guinea	0.7	1.1	3.5	1.7	2.3	89
Liberia	1.2	1.3	3.8	2.4	3.0	16
Madagascar	1.9	3.5	4.6	2.1	2.9	43
Nigeria	17.9	19.6	4.8	1.2	2.7	225
Sierra Leone	0.8	1.2	3.5	2.3	2.8	59
Togo	0.1	0.2	3.9	1.8	2.6	45
All	39.8	41.3	4.1	1.2	2.5	66

Source: FAOSTAT (2015).

Tree crop farming subsystems

Three tree crop farming subsystems are identified for sub-Saharan Africa. The most widespread is FRS, which is mainly focused on low input production of cocoa, oil palm, rubber and coffee along with food crops (Ruf 1995). The SIS employs innovations from agricultural science to achieve high yields. The IPS is similar to the SIS in its use of improved seed-fertilizer technologies and pest and disease management but is distinguished by the scale of operation and a much higher capital:worker ratio than either the FRS or SIS. It mainly grows oil palm and rubber. All three subsystems are connected to global markets and therefore subject to global competition.

The forest rent subsystem

The typical west African FRS is operated by a village-based household producing tree crops for global markets. The term 'forest rent' refers to the subsystem's reliance on the nutrients tied up in the forest biomass which underlie the productivity of this system. On an annual basis a portion of the nutrient stock is used up and exported out of the system eventually leading to nutrient depletion and declining productivity. The system may remain productive for 20 to 30 years depending on a variety of factors, but eventually the land becomes fatigued. Rather than trying to rejuvenate soil fertility through application of imported nutrient inputs, cash-strapped farmers either seek out new forest to create a new farm or convert the fatigued FRS to a less demanding tree crop such as rubber or oil palm (Ruf 2008). The cocoa and oil palm FRS have both played major roles in deforestation and forest degradation across west Africa as farmers have exploited forest rents since the 1960s (Gockowski and Sonwa 2011).

The subsystem consists of a mix of production systems. The most common are coffee-, cocoa-, oil palm- and rubber-based, with the cocoa-based FRS most frequently encountered. Analysis of the cocoa-based FRS is based on data gathered by the Sustainable Tree Crops Program (STCP) from 2001 to 2012. STCP was a public-private partnership

Table 9.3 Demographic characteristics of household heads in the cocoa-based forest rent subsystem

	Cameroon	Côte d'Ivoire	Ghana	Nigeria	All
Age of household head (yrs)	51	49	47	56	51
Proportion of household heads younger than 40 yrs (%)	28	30	40	21	30
Length of residency (yrs)	32	27	34	38	33
Migrant (%)	26	56	41	48	44
Female head of house (%)	2	4	11	11	7
Primary school certificate or higher (%)	60	42	58	7	44

Source: IITA (2002).

Note: Sample sizes for Cameroon, Côte d'Ivoire, Ghana, Nigeria and All were 906, 1140, 908, 1081 and 4035 respectively.

between west African tree crop research institutions, the International Institute of Tropical Agriculture (IITA) and the global chocolate industry. The programme was sponsored by The United States Agency for International Development (USAID) and the World Cocoa Foundation.

The typical FRS household of West Africa is headed by a 51-year-old male with limited education (Table 9.3). Four in ten household heads are migrants or descended from migrants. Female-headed households are less common, often due to restrictive, customary tenure institutions (Berry 1988). The cocoa belt of Ghana, where one in every five producers is a woman, has the highest agricultural participation by women in Africa. Berry (1988) reported female ownership of cocoa farms in excess of 50 per cent in the 1970s in certain localities of Ghana, which she attributed to matrilineal inheritance institutions common among the Akan.

The mean cocoa FRS total landholding ranges from 7 to 19 ha (Table 9.4), reflecting different land pressures facing households at the country level. In Cameroon, over half the typical household's land was either lying fallow or in forest in 2001, compared with 12 per cent in Nigeria. While the average cocoa planting is 4.7–6.4 ha per farm, the majority of cocoa plantings are small (Figure 9.2). The 20 per cent of farmers with the largest farms (average 15 ha), account for over half of the total cocoa hectares in West Africa, while the 20 per cent of farmers with the smallest farms (average 1.3 ha) represent only 4 per cent of the cocoa area.

Differences in farm size affect the producer's choice of technology. Farmers in the lowest quintile have developed land-sparing technologies such as multi-strata agroforests often adjacent to the producer's homestead, that benefit from the concentration of nutrients emanating from the household: kitchen refuse, animal manure, night soil, food processing and wood ash. Large farmers opt for labour-saving innovations such as herbicides while employing sharecroppers to farm larger areas.

The cocoa FRS household typically allocates 1 to 2 ha of land for food crop production (Table 9.4). Food crop systems tend to be managed by women with men mainly responsible for slashing the fallow field in preparation for planting. Food production is typically for household consumption and can represent a significant portion of the overall household income. In the cocoa belt of Côte d'Ivoire, home-produced consumption accounted for 32 per cent of total agricultural household income (Benjamin and Deaton 1993).

Figure 9.2 Distribution of household area planted to cocoa in the cocoa belt of west Africa (n=4078).

Source: IITA (2002).

In areas with good access to urban centres, commercial food production takes on increasing importance. More of the household's land and labour is allocated to food crop production, and less to tree crops: FRS cocoa producers earning more than 40 per cent of cash income from food crop sales cultivated 2.7 fewer hectares of tree crops than those below this threshold (STCP unpublished data). Both eastern Côte d'Ivoire and eastern Ghana are examples of regions where the majority of households have transitioned out of cocoa-based FRS to the root and tuber farming system in response to rapidly growing urban centres. It should be said that these transitions have also been driven by the disappearance of the forest rent following 60 years of cocoa cultivation.

Food crops are often grown in association with newly planted tree crops during the establishment period. These associations contribute to the household's food basket while also providing shade to the young cocoa and coffee seedlings. In land-abundant areas such

Table 9.4 Average land and labour endowments of cocoa-based forest rent subsystem

	Cocoa	Food crops	Other tree crops	Fallow fields	Forest land	Total farm size	Family size	Land-labour ratio
	-----hectares-----						No.	
Cameroon	6.0	2.5	0.3	3.6	6.4	18.8	12.9	1.5
Côte d'Ivoire	5.6	1.6	0.3	3.4	1.9	12.9	10.4	1.2
Ghana	6.4	1.5	0.7	1.3	0.9	10.7	9.7	1.1
Nigeria	4.7	1.3	0.5	0.7	0.2	7.4	9.9	0.7

Note: Total sample size for this study was 4035.

Source: IITA (2002).

as south central Cameroon, the FRS household also produces food crops in a fallow rotation system. By commodity, the most important food crops grown in the cocoa-based FRS are cassava, plantain, cocoyams, maize, yams and upland rice. Another important source of household sustenance comes from various fruit trees commonly found in the cocoa field and elsewhere on the farm. These generally include avocado, citrus, mango, bush mango, African breadfruit and the African plum. Most typically these perishable crops add variety to the household diet, although when market access exists they can contribute significantly to household income.

It is common for FRS farmers to manage several different tree crop production systems. In decades past, differences in the seasonal labour demand of cocoa and robusta coffee allowed for their joint production by many smallholders in Côte d'Ivoire. However, the emergence of Vietnam in the 1980s as the largest global producer of robusta coffee depressed prices. Undercut Ivorian coffee producers responded by uprooting and replanting with oil palm and rubber (Cheyns and Raffleau 2005; Gockowski and Sonwa 2011). Palm oil is the most common cooking oil in the humid lowlands of west and central Africa, and unlike cocoa, coffee or rubber, it is in great local demand by both rural and urban households. One in five cocoa FRS households produces oil palm for commercial purposes (International Institute of Tropical Agriculture unpublished data).

Most mature cocoa plantings in Ghana and Côte d'Ivoire FRS are grown in full sun or at best limited shade. With more light the cocoa tree gives higher yields but can become physiologically stressed by high levels of production and as nutrients in the system deplete. Since the late 1970s the locus of cocoa production in both countries has moved from east to west as farmers have used up the forest rent. Shaded cocoa fields are more common in parts of Cameroon and Nigeria where some have been in continuous production for nearly 100 years (Jagoret et al. 2011) (Figure 9.3). This is normally attributed to the greater capacity for nutrient cycling when deep-rooted shade trees are included in the production system.

Figure 9.3 A farmer in his shaded cocoa plantation, Nkhol Bang village, Central Region, Cameroon.

Source: Cynthia Gidoin.

Table 9.5 Adoption of improved (F1 hybrid seedlings) versus unimproved (local land race) cocoa planting material in cocoa-based forest rent subsystems (%)

	<i>Unimproved</i>	<i>Improved</i>	<i>Both</i>
	<i>Producer frequency of use</i>		
Cameroon	81	6	14
Côte d'Ivoire	88	9	4
Ghana	58	27	15
Nigeria	91	7	3
Grand total	80	12	8

Source: IITA (2002).

The majority of cocoa FRS households use seeds taken from their own tree stocks, instead of certified hybrid seeds (Table 9.5). Ghanaian cocoa producers reported the highest usage of improved planting material, but the majority still used their own planting material despite acknowledging the superior performance of hybrid selections (Ahenkorah et al. 1987; Edwin and Masters 2005; Gockowski et al. 2011). The use of improved

Figure 9.4 *Phytophthora megakarya* rot on cocoa pods, Ozom, Lékié Department, Cameroon.

Source: Martijn Ten Hoopen.

hybrid seed is higher among smallholder operators of oil palm and rubber FRS, mainly due to the production and distribution of improved planting materials by the industrial plantation system who make it available to FRS smallholders.

Most operators of the FRS do not use fertilizers (Table 9.6), as explained earlier. Pesticides are more frequently used, especially fungicides in Nigeria and Cameroon where a particularly toxic strain of black pod disease (*Phytophthora megakarya*) mandates their use to prevent potential total crop failure (Figure 9.4). In addition to black pod disease, the majority of cocoa FRS households across all countries of the cocoa belt, spray insecticides to control ubiquitous plant-sucking insects known as capsids (*Distantiella theobromae* and *Sahlbergella singularis*). Capsid resistance is a recurrent problem faced by producers.

Ownership of durable goods is low in forest rent tree crop farming subsystems (Table 9.7). Pesticide sprayers are used by more than half of FRS households, with a slight difference between larger and smaller farms. The limited availability of simple transport such as single axle tractors, pushcarts and wheelbarrows means that most cocoa is transported from the field to the farm gate by human head load.

The size of the tree crop holding determines overall labour demand. For a representative, 6.7 ha cocoa-based FRS farming system just north of Yaoundé, Cameroon, the estimated annual agricultural labour demand for the farm was 629 days, of which 54 per cent was allocated to cultivation of the mixed food crop field, 24 per cent to the cocoa FRS system and the remaining 22 per cent to tomato production. Some tasks are gender-specific and some are undertaken jointly. Overall, women were estimated

Table 9.6 Percentage of producers using agrochemicals on cocoa and food production systems in the cocoa-based forest rent farming system

	Food crops		Cocoa		
	Fertilizer	Pesticides	Fertilizer	Insecticide	Fungicide
Cameroon	3.9	6	1	46	81
Côte d'Ivoire	3.7	13	27	61	18
Ghana	9.4	59	3	32	21
Nigeria	5.3	5	3	81	95
All	5.4	10	10	56	53

Source: IITA (2002).

Table 9.7 Frequency of tool ownership among FRS households by size of cocoa planting (%)

	Farms > 4 ha	Farms ≤ 4 ha	All
Chainsaw	4.2	1.8	2.9
Irrigation pump	2.8	1.1	1.9
Pick up truck	3.1	1.9	2.5
Pushcart	11	4.9	7.5
Wheel barrow	18	14	15.8
Knapsack sprayer	51	46	48.1
Motorized sprayer	13	5.5	8.8

Source: IITA (2002).

Note: Sample sizes for the three cocoa farm size categories were 1850 for farms > 4 ha, 2185 farms ≤ 4 ha and 4035 for all sizes respectively.

Figure 9.5 Total monthly crop production labour requirements for men and women on a forest rent farming subsystem in southern Cameroon. This example system comprises 2.6 ha cocoa, 0.4 ha commercial tomato and 0.3 ha in a mixed food production system.

Source: Author's calculation.

Figure 9.6 Cocoa bean extraction after the cocoa pod harvest.

Source: Régis Babin.

to have supplied 58 per cent of the labour and men 42 per cent. Prior to the introduction of cash crops such as cocoa and tomatoes, women accounted for an even higher proportion of total labour supply (Boserup 2007; Guyer 1984). Women's workloads are highest in the months of March and again in September when field preparation for mixed food-crop fields occurs (Figure 9.5). Peak demands for men occur in March when field clearing of the wife's mixed food-crop field intersects with tomato field preparation, and in May when tomato weeding coincides with cocoa pest and disease control. Addressing labour shortages during periods of peak workloads is most commonly achieved by working in reciprocal labour exchanges with family and friends or hiring temporary workers (Figure 9.6).

For many large landowners, the labour demand often exceeds the household's (family) capacity. Most large landowners meet their labour demand by employing sharecroppers. Cocoa producers with total landholdings above 4 ha were twice as likely to engage sharecroppers as those below (IITA unpublished data). However sharecropping is not without its issues (Box 9.1).

Box 9.1 Ethnicity, migrant labour and farm size in the cocoa belt of Côte d'Ivoire

A village chief in the cocoa growing region of southern Côte d'Ivoire explains how access to labour influences the scale of cocoa farming:

You will notice that the Mossi own large farms and produce a lot of cocoa because they recruit workers while other producers cannot afford workers. The Mossi go to Burkina Faso and bring back their brothers to come and work as farm workers, and so they establish large farms . . . The other producers do not recruit workers and so work with their children. However, since most of the children attend school, they cannot help every day. That is why producers who are not Mossi cannot create large farms . . . else who will work in them? If you cultivate a large farm and have no workers, all your cocoa will rot in the bush and you would have toiled for nothing.

Source: Excerpt from Bazzi-Veil and Kambou (2002).

The most typical share-cropping arrangement in the west African cocoa sector involves sharing the commodity 67:33 between the landowner and the sharecropper, with the landowner covering the cost of purchased inputs. Sharecroppers are generally under the age of 30 and from impoverished rural areas such as the Mossi plateau in Burkina Faso, the western highlands of Cameroon, eastern Ghana and the southeast of Nigeria. The incidence of poverty among shareholders is high, but for some it may be transitory if they are able to acquire their own cocoa farms. This is becoming increasingly difficult, and sharecropper households comprise a disproportionate number of the chronic poor in the tree crop farming regions of west Africa.

When labour markets or low commodity prices do not allow the use of hired labour, either the scale of the farm will be adjusted by abandoning less productive lands, or children from within the household may be asked to forsake their education and shoulder the extra burden (Bazzi-Veil and Kambou 2002).

The smallholder intensified tree crop farming subsystem

In the SIS, the majority of farmers have adopted innovations developed by agricultural research that has significantly increased productivity and household income. These are principally improved seed-fertilizer technologies and the chemical and biological management of pests and diseases. The areas where the SIS predominates are few, and ephemeral as a result of commodity price fluctuations and/or unsustainable policy interventions.

At the start of the 21st century, more than 100 years after the establishment of the cocoa industry by the migrant farmers of Ghana, no area in the west African cocoa belt could be defined as intensified, and there was essentially zero support for farmers' use of modern inputs. However, starting in 2001, fertilizer and pesticide programmes implemented by the Ghana Cocoa Marketing Board began to transform the cocoa FRS in the western region of Ghana (at least for a time). By 2009, these programmes generated yield growth rates comparable to the green revolution in India. These gains were achieved primarily by supplying subsidized fertilizers and pesticides to smallholders on a significant scale. At a programme cost of US\$172 million, 130,000 metric tonnes of cocoa fertilizer were purchased and distributed to farmers at subsidized prices by the Ghana Cocoa Marketing Board in 2010/11, mainly in the Western Region.

A survey of 4,357 participants in a 2010–2011 farmer field school training programme by the STCP revealed that between 62 and 79 per cent of producers from six growing districts in the Western Region had applied subsidized fertilizer in 2009. Only 20 per cent of producers from other regions reported likewise. A more detailed survey of 170 producers in 2011 in the Bia district, Western Region, found that 75 per cent of producers had applied fertilizers, on average 225 kg/ha, which was largely responsible for a doubling in yield. Women used fertilizers more commonly than men; however, due to smaller farms and poorer access to credit, they used less fertilizer per hectare.

Farmers create their cocoa farms by planting a newly cleared field contemporaneously with food crops, primarily cassava and plantains in April or May. The location of each planted seed is marked with a stake so that as the field develops, the young cocoa seedling is not accidentally weeded. This practice, known as 'planting at stake', is common across west Africa. Despite the higher productivity of hybrid cocoa in farmers' fields, less than 7 per cent of bearing acreage was planted to hybrid cocoa. Unlike agrochemical innovations, women cocoa producers have lower use of hybrids than men. The average hybrid area planted per woman was less than half the area planted by men.

Fertilized cocoa farms are essentially no-shade systems, with an average of only six trees per hectare. These levels of shade are low compared with the cocoa-based FRS of west Africa (Gockowski et al. 2010). CRIG recommends no more than 15 shade trees per ha for improved, fertilizer-responsive cocoa varieties, based on over 20 years of shade-fertilizer trials (Ahenkorah et al. 1987).

Relative to the FRS, the cocoa-based SIS has a higher use of pesticides to control cocoa pests and diseases. Capsid bugs account for the largest total pesticide cost. This is followed by black pod disease, which requires an average application of 1.9 kg copper fungicide per hectare. Herbicide use is also increasing and applied to approximately one out of every three hectares of harvested cocoa. Cheaper generic formulations of glyphosate on the market have made herbicide use affordable. Herbicide use is more frequent among farmers with larger field size because it means less labour to control weeds manually (Table 9.8). As with fertilizer, women cocoa producers participate equally with men in the increased use of phyto-sanitary products (Gockowski et al. 2011).

Empirically, the adoption of chemical innovations is relatively independent of cocoa farm size (Table 9.8). However, the intensity of fertilizer use per hectare declined significantly with farm size ($\rho = -0.25$) with a farm of 1 ha receiving twice as much fertilizer per hectare as a farm of 10 ha (Table 9.9).

Analysis of the ratio of cocoa land to total farmland suggests that adoption of the SIS is associated with an increase in cocoa specialization. More than one-third of SIS producers indicated complete specialization in cocoa production (100 per cent of planted area is cocoa). Specialization could have repercussions for household food security if cocoa crowds out household crop production or if local food markets are incomplete. Analysis showed the share of staple food consumption purchased in local markets was negatively related to farm size (Figure 9.7). Of the producers indicating complete specialization, nearly one-third made no staple food purchases, while only 25 per cent indicated complete dependency on market purchases. The majority grew mixed associations of cocoa and food crops, with one of four food production strategies: (1) fruit tree integration in the shade canopy of the cocoa field, (2) shade-tolerant cocoyam at low density in the understory, (3) plantain and cassava with cocoa seedlings when replanting gaps in the cocoa canopy and (4) food crops (cocoyam, plantain, and cassava) during the first several years following establishment of new cocoa or replanting of old cocoa (Figure 9.8).

Table 9.8 Frequency of chemical innovation by size of cocoa holding in the western region of Ghana, in 2011 (%)

	Size of cocoa holding (quartiles*)				
	I	II	III	IV	All
	----- producer adoption-----				
Fertilizer	76	60	78	86	75
Fungicide	66	58	71	69	66
Insecticide	88	88	93	100	92
Herbicide	24	33	39	36	33
	----- proportion of bearing cocoa treated -----				
Fertilizer	78	65	72	85	79
Fungicide	68	61	78	74	73
Insecticide	93	89	90	99	95
Herbicide	24	32	36	31	32

*Farm size categories are defined as: quartile I (<2.83 ha), II (2.83 to 4.85 ha), III (4.85 to 9.30 ha), and IV (9.30 to 61 ha).

Source: IITA (2011).

Table 9.9 Intensity of fertilizer application as a linear function of farm size in the cocoa SIS

Farm size (ha)	Predicted fertilizer use (kg/ha)
1	232
3	204
7	147
10	105

Source: IITA (2011).

Figure 9.7 Proportion of staple food crop consumption procured from food markets versus home production for four farm size categories in Bia district of the Western region of Ghana.
Source: IITA (2011).

Figure 9.8 Newly planted cocoa associated with cassava and plantain as temporary shade, in Bia District, Ghana.
Source: Valentina Robiglio.

The area under newly established cocoa is thus critical in ensuring the household's food security. This is particularly so for the smallest producers, most of whom did not include a separate food crop production system in their farm. The problem faced by the producer who relies on the food production from among newly planted cocoa is the lumpiness of this output in time. With the average life of a cocoa farm ranging from 20 to 35 years, new planting or replanting may not occur every year.

The industrial plantation subsystem

The IPS first emerged during European colonization in the late 19th and early 20th centuries. Plantations with historical links to this period include Unilever palm oil plantations in the Democratic Republic of Congo, the Firestone rubber plantations in Liberia, and the rubber, oil palm and banana plantations on the rich, volcanic soils of Mount Cameroon operated by the government-owned Cameroon Development Corporation (CDC), with the original plantations established by German colonials prior to World War I.

The oil palm IPS is by far the most common industrial farming system, followed by rubber. The ownership of this subsystem is variable and often mixed, including private corporations, state governments and sovereign wealth funds. In some countries of west and central Africa, well-connected political elites are often proprietors of IPS. In the years after independence, many countries established state-run industrial plantations, such as the aforementioned CDC.

In the case of oil palm the perishable nature of harvested, fresh fruit bunches necessitates the co-location of production and milling. This limits the optimal size of the processing unit and accompanying plantation area as at some point diseconomies of scale will begin to increase costs.

The IPS pursues a high fixed-cost, profit-maximizing business model. Capital investments are high and upfront. In the case of an oil palm plantation, capital inputs include oil milling facilities, farm-to-factory roads, vehicle fleets for transporting the commodity, heavy equipment for field clearing and facilities for the production of hybrid seedlings (Figure 9.9). Capital investments also include worker housing and social amenities such as health clinics, recreational facilities and schools. IPS investments in an oil mill facility and vehicle fleets expand the demand for fresh fruit bunches and enables the development of associated SIS out-grower (contract farming) schemes linked to the IPS. The IPS investment also provides a market for independent smallholders who do not wish to enter into contract farming arrangements.

The smallholder tree crop system may be affected both directly and indirectly by IPS. Out-grower schemes are especially common in the oil palm sector. The IPS enters into a contractual relationship with selected smallholders living relatively close to the processing unit. In exchange for the provision of marketing services, technical support, input supply and credit, the smallholder is obligated to deliver the tree crop commodity to the IPS at an agreed price (Vermeulen and Goad 2006). In this manner farmers can gain access to modern agricultural technology in a complete package.

Smallholders may also benefit from IPS investments in skills training received while employed by an IPS or by employing former IPS workers with such experience. The rapidly growing smallholder rubber sector in Côte d'Ivoire is a case in point (Ruf 2008). Smallholders are employing the services of rubber tappers and tree grafters who have been trained and employed by an IPS.

Not all interactions are so positive. In some cases communities may lose some of their access to forest land and waters that are important livelihood assets for the poor. These assets, and the benefits that they generate, are difficult to measure and evaluate.

Figure 9.9 Relative investment costs for a \$45 million industrial plantation subsystem of 6000 ha, employing 1,400 workers.

Source: Author's update of World Bank project evaluation.

Trends and drivers of change in the tree crop farming system

Population, hunger and poverty

Population density in the humid lowlands of west and central Africa was historically low mainly due to disease pressures. However as modern medicine has developed, this has permitted migration into regions that 100 years ago were not considered habitable. Often these migrations were motivated by the development of tree crop export markets. As lands were acquired and tree crops planted, the demand for labour grew – this has been met largely by migrant workers from outside the humid lowlands with the exception of Ibo sharecroppers from southeastern Nigeria. In precolonial times much of the land was not inhabited and covered in tropical rainforest; today the average rural population density is 66 persons per square kilometer, the forest is gone and 40 per cent of the population live in extreme poverty (Tables 9.1 and 9.10). Angus Deaton (1999), the Nobel winning economist, holds that the font of labour in west Africa and elsewhere in the developing world that is willing to work for near subsistence wages is a principal factor explaining the trendless behaviour of commodity prices over the last 100 years.

Household endowments of land and labour

The theory of induced innovation can be used to explain the historical development of agriculture in countries with differing endowments of land and labour (Hayami and Ruttan 1985; Hicks 1932). In countries where land was abundant relative to labour, such as the United States and Canada, science focused on technologies that used land and capital while saving on labour. In economies where labour was abundant but land was scarce (e.g. rural Japan), innovation focused on land-saving and labour-using technologies.

Table 9.10 Population densities of the three principal farming systems of the humid low land tropics in 2010

<i>Farming system</i>	<i>Rural population density</i>
	<i>Pers/sq km</i>
Tree crops	66
Root and tuber	26
Forest-based	6.5

Source: FAOSTAT (2015).

In Africa, the tree crop farming system has double the rural population density of the root and tuber farming system, and nearly ten times the density of the forest-based system (Table 9.10). Thus, the choice of commercial tree crop farming (high value, intensively managed crops) where markets are available may be a response to increasing land pressure. As discussed earlier, household food production and employment depends on the availability of land, farm size and degree of farm intensification and specialization. Within the tree crop farming system there is wide variation in endowments of land and labour (Table 9.4). In parts of Cameroon, farmer access to forest land is essentially unlimited given the capital, tools and labour available for its exploitation. In such situations, FRS subsystems that optimize the return to labour prevail. In southeast Nigeria, higher population pressure, inalienable land rights and patrilineal inheritance have resulted in extreme fragmentation of the farming system. Here rural livelihoods are heavily dependent on employment in the non-farm economy.

Urbanization

Another major driver of change in the tree crop farming system is the rapid growth of urban centres. Urban populations in west Africa are doubling every 14 years, swelled by a tide of rural to urban migration. Other things being equal, this causes the price of food to rise relative to tree crops, leading to increased quantities of food grown and supplied, and decreased quantities of export commodities. Offsetting this influence is an increased preference for convenience foods by urbanites, which has increased imports of rice and wheat. Countries with the marketing infrastructure to export tree crop commodities can use that infrastructure to also import rice and wheat. Thus, there is a complementarity between tree crop production and the importation of staple food crops. Capital investments in port facilities and road infrastructure will facilitate both types of trade. The foreign exchange generated by the production of tree crops also ensures the capacity to import these staple commodities.

Hunger and poverty hotspots

Rural populations are still growing, albeit at rates significantly lower than those of urban populations. This continued pressure on the natural resource base leads to increasing land fragmentation and, in areas such as southeast Nigeria, has led to soil nutrient depletion. This can entail a descent into poverty. Eventually, households are either forced to exit the agricultural sector or to seek off-farm employment.

Within most commercially oriented tree crop farming regions, there are communities of landless workers engaged by larger farmers. This segment of the population is typically the most vulnerable. They are often dependent on the landlord for lodging and meals. With little in the way of support structures and social capital, some workers have reported abusive treatment.

The distribution of landholdings within many tree crop farming communities is not as egalitarian as one might expect under customary tenure institutions. As shown in Figure 9.2, the distribution of farm size is skewed. Thus, even in relatively prosperous regions, a significant number of smallholder households face poverty and hunger. In the western region of Ghana, which is the leading region for cocoa production, 27 per cent of children under the age of five were estimated to be chronically malnourished in 2008 (Ghana Statistical Service 2009).

Markets and trade

As part of global markets, the African tree crop farming system is impacted by the events occurring thousands of miles from its shores. When Vietnam resettled nearly one million persons in the central highlands in the mid-1980s and offered subsidized credit for the creation of robusta coffee farms, the impact was felt around the coffee-growing world. As Vietnam established itself as a major producer, the ensuing decline in price led many west African farmers to abandon coffee production (Figure 9.10).

The global production of palm oil has increased by 141 per cent since 2000 and now represents 40 per cent of the global vegetable oil supplies, with an annual production of 65.5 Mt (USDA 2013). Indonesia and Malaysia account for 53 and 33 per cent of global output, respectively. Demand for palm oil has been spurred by the growing global market for biofuels. Biodiesel feedstock demand in Europe increased from 0.4 Mt in 2006 to 1.9 Mt in 2012 with a projected increase to 2.6 Mt by 2020 (Gerasimchuk and Koh 2013). The development of biodiesel from palm oil is expected to keep global prices firm, which is important for the encouragement of greater foreign investment in this industry to provide jobs and state revenues.

Numerous studies have found tree crop producers in west and central Africa responsive to price incentives (e.g. Akiyama and Trivedi 1987; Gilbert and Varangis 2003). In general, the supply response to an increase in price will be greater in the long term because of the biological lags between planting or replanting and production that characterize most perennial tree crops. In the short term, the producer is able to adjust only his or her labour or the quantities of inputs applied. If input markets and rural credit are not well developed, the short-term supply response to price will be further muted.

Globally, increased commodity demand, including a growing middle class in China, India and South East Asia, and European policies mandating the use of biofuels as a tool in meeting Kyoto CO² commitments, have contributed to upward pressure on prices. Prices have increased on average between 3 to 6 per cent per annum ($P < 0.01$) for at least 21 years (Figure 9.11). Robusta coffee is the only tropical tree crop not to have experienced a significant increase in price over this period. Wheat and rice, the two most significant African food imports, also experienced increases in price but at rates lower than the major African tree crops. This implies an improvement in the agricultural terms of trade for the tree crops sector in the humid forest zone of Africa. Tempering the upswing

Figure 9.10 Change in robusta coffee production and acreage in West Africa and Vietnam, 1980–2012.

Source: FAOSTAT (2015).

Figure 9.11 Monthly average global prices for selected tree crop commodities, 1991–2012.

Source: IMF Primary Commodity Prices, Monthly Data (2015).

in global commodity markets has been a significant increase in the price of NPK fertilizer at annual rates in excess of tree crop commodity prices.

Tropical commodity prices also tend to be highly variable and are often correlated with increasing the riskiness of smallholder intensified production systems, particularly where crop insurance is not available. The volatility of smallholder tree crop income is thus impacted by both price risk and production risk.

Concerns over the environmental and social impact of tree crop farming have been raised in recent times. The rapid expansion of extensive cocoa and oil palm production systems in the last 20 years is often cited as a major cause of deforestation and forest degradation (Gockowski and Sonwa 2011; Norris et al. 2010). Certified production systems based on ‘good agricultural practices’ are being proposed to west African cocoa and oil palm farmers by partnerships of environmental NGOs and industry stakeholders in order to address the lack of innovation and the degrading natural resource base. Programmes such as the Roundtable on Sustainable Palm Oil, UTZ certified, Fair Trade Certified and Rainforest Alliance Certified seek to assure Western consumers that the chocolate or coffee that they consume has been produced in an environmentally and socially sustainable fashion. After training farmers on good agricultural practices, which includes both environmental and labour practices, third-party agencies then certify that sustainable practices are in place. Facing class-action lawsuits and potential prohibition of cocoa from Côte d’Ivoire over the use of child labour on west African farms, major producers of chocolate such as Hershey’s chocolate, Mars and Nestlé have committed to third-party certification, with Mars and Hershey’s both committed to sourcing 100 per cent certified cocoa by 2020. Currently premiums range from \$140/t to \$200/t of certified cocoa. The producer-benefits from certification depend on: (1) the extent to which consumers

are willing to pay premiums for process attributes such as ‘child labour-free’ or ‘shade-grown’ cocoa, (2) the efficiency of market actors in passing through premiums to the producer of certified cocoa, and (3) the productivity of the proposed certified practices relative to the farmer’s typical practice (Gockowski et al. 2013).

Policies and institutional reforms

In response to growing global demand for palm oil, rubber and cocoa, many large transnational corporations are in the process of investing in production and processing facilities in various countries of west and central Africa. These investments have been encouraged by government tax breaks and long-term concessions of land at minimal cost. While such investments are able to find abundant land in the underpopulated regions of the Congo basin in Central Africa, finding labour is more problematic. In land-scarce west Africa where labour is abundant, the opposite is true. Cameroon has moderate land and labour endowments and has been particularly attractive to such initiatives. While there are definitely risks of alienation and loss of land access, the remarkable reduction in rural poverty achieved in Indonesia and Malaysia through policy-led intensification of smallholder palm oil production cannot be denied (Sheil et al. 2009; Vermeulen and Goad 2006). At the same time, this development outcome has come at an environmental cost.

Stabilization or marketing boards were introduced during the colonial era, purportedly to buffer producer income from weather and price shocks. The boards established stabilization reserve funds from surpluses generated during periods of price spikes, which were to be drawn upon to support prices when they fell below their long-term average. While price volatility was reduced, the long-term average price received by producers typically ranged between 40 and 55 per cent of the free on board (FOB) border price. Producers had very little incentive to innovate their production systems at these low prices. In essence, these structures became important sources of state revenues that were often beset by rent-seeking behaviour and ill-advised investments.

In the 1980s and 1990s, the dismantling of marketing boards was often a condition of structural adjustment. Almost all of these boards are now closed, with the notable exception of the Ghana Cocoa Board. In their place the private sector has assumed marketing functions. In Cameroon and Nigeria, producers have benefited from a higher share of the FOB border price, which has been trending upward. In Côte d’Ivoire, although marketing is now a private sector activity, high export taxes have reduced producer prices.

While the improved price incentives in Cameroon have led to an 8 per cent growth rate in cocoa production since 2000, nearly all of the additional growth has come from the area expansion of the FRS. This is in contrast to Ghana, where increased land productivity has accounted for the bulk of sector growth since 2000. Cameroon completely liberalized its markets in 1994 and no longer taxes producers. Côte d’Ivoire liberalized marketing in 1994 with the elimination of the CAISTAB (La Caisse de stabilisation et de soutien des prix des productions agricoles), but the government continues to collect taxes from exporters, which are passed along to producers. Ghana maintains its marketing board, which annually sets a pan-territorial producer price at a level of 70 per cent of net FOB.

Empirically, cocoa output in Ghana has grown at a rate of nearly 6 per cent since the mid 2000s and is a success story for the country and the region (Kolavalli and Vigneri 2011). Underlying this achievement was the adoption and application by smallholders of

granular fertilizers (subsidized) and an increase in the producer's share of the 'net' FOB price (Gockowski 2012). Other countries in the region are considering such policy-led intensification efforts.

Several innovations in institutions have recently emerged, which are improving the delivery of goods and services. They include the provision of fungicides and insecticides on credit by purchasers of cocoa in Nigeria and Cameroon. Similarly, cocoa fertilizers have been provided on credit by Ghana's licensed cocoa buying agents. In both cases the employment of clerks from the community has helped firms to overcome information constraints that prevent formal financial institutions from effectively administering small loans to smallholders (Gockowski et al. 2008).

Land tenure institutions in areas of higher demographic pressure appear to be achieving more secure tenancy through a mix of customary and statutory law. In west Africa, unallotted idle lands not under protected status as national parks or forest reserves, are now miniscule relative to 30 years ago when new land for farming could be easily obtained. Blocher (2006) noted that the 1990s and 2000s witnessed a considerable slowdown in the allocation of land by Ghanaian chiefs under customary law. Persons acquiring land during this period did so either by outright purchase, generally accompanied by a transfer of land title, or through a variation of the 'abunu' sharecropping tenancy institution.

In the abunu arrangement, Ghanaian landowners who have customary rights to land but lack sufficient labour for its development sometimes negotiate a contract with landless workers to develop forest land into a cocoa or oil palm farm. Once the farm was developed and producing (usually six to eight years), the improved land with its productive tree assets was shared equally between the worker who created the farm and the landowner. In 2010, one in every seven cocoa farms and one in every six oil palm farms had been acquired through such arrangements (Gockowski et al. 2011). Customary law recognizes this transfer of stool land from the landowner to the worker and accords the worker inheritable rights to pass this land onto his or her heirs. This institution provides an avenue for asset development among the landless and has important poverty-reducing impacts, but the incidence of such arrangements appears to be waning. Ruf (2008) reported a similar institutional innovation that emerged in the 2000s in Côte d'Ivoire in both the cocoa and rubber subsectors.

Science and technology

The green revolution was founded upon the development of improved crop varieties and the increased use of inputs which increased yield when adequate water, nutrients, pest-control and sunlight were also present. The multibillion-dollar development of the oil palm sector in South East Asia was similarly the result of sustained funding over the course of the last 50 years in genetic and agronomic research. The extent to which South East Asian results will spill back into Africa, with the wave of oil palm investment by South East Asian companies, remains to be seen. The largest benefit may be the introduction of improved clones of oil palm, and their multiplication and distribution to satellite growers.

Transformative growth in the agricultural sector is closely linked to the adoption and spread of improved varieties. Genetic improvement in Africa has been impeded by a lack of sustained funding, which is particularly important given the biological lags associated with tree crops. On the supply side, long lags between planting and production slow the development of new cocoa varieties by research. On the demand side, farmers

have infrequent opportunity to improve the genetic quality of their tree stock because of the long productive life of perennial tree crops. Most farmers will only replant after 25 or more years, which is a long time to wait for repeat customers. The limited demand for improved cocoa planting materials has thus far restricted the research and development of new varieties almost exclusively to the public sector. Despite these impediments, improved planting materials have been developed for rubber, palm oil and cocoa.

However, the lack of local availability of improved planting materials has been a major limitation to their adoption. In all countries, government-sponsored seed gardens and nurseries have been the main source of improved cocoa materials. Unfortunately, nearly all of these institutions have been beset by logistical failures and supply constraints (Asare 2011). Farmers can spend an entire day travelling to a seed production unit, only to be told that there are no seed pods available.

Where research budgets have been stable and adequately funded over the years, such as the CRIG, innovations such as cocoa fertilizers and improved planting materials offer the potential for a broad-based pathway out of poverty.

Natural resources and climate

Land degradation is a common outcome of African agriculture. The negative nutrient balances which characterize most African farming systems are a fundamental constraint to rural development in sub-Saharan Africa (Sanchez et al. 1997). Average losses of N, P_2O_5 and K_2O were 42, 10 and 23 kg/ha of cocoa in Côte d'Ivoire, and very similar in Ghana, at 40, 8 and 23 kg/ha of cocoa (Stoorvogel and Smaling 1990). Productivity will gradually decline as nutrients are exported and not replaced. When forests were abundant, the sustainability of the farming system was based on long-term fallow rotations. This is no longer possible for the majority of tree crop producers, and an integrated approach to improving the degraded fertility status of African soils is essential.

With degradation of the tree crop system, build-ups of pests and disease inoculum can prevent the rehabilitation and replanting of the production system, and they force the farmer to diversify. The disappearance of mammalian and avian seed dispersers is another degradation which affects forest regenerative capacity. Local climatic conditions are also impacted by vegetation changes as the landscape transitions from forest to a patchwork mosaic of scrubland and agricultural use.

In nearly all instances, the tree crop farming system of Africa is rainfed and not irrigated. At the landscape level, a preponderance of tree crop production systems will generally improve water quality relative to annual cropping systems, through lower levels of sedimentation and soil erosion with year-round vegetation cover. There is some concern about the potential misuse of agrochemicals and the effects on water resources. Although pesticide use is still well below the levels found in developed country agriculture, these concerns are being addressed in the certification programmes mentioned earlier by the introduction of management practices such as riparian buffer strips and ultralow volume (ULV) pesticide applications.

Tree crop farming systems have played a major role in the near disappearance of rainforest in west Africa, where Mayaux et al. (2013) estimated that only 12 million ha of dense rainforest¹ remains compared to 179 million ha in Central Africa. Tree crop production accounts for 1 in every 4 ha farmed in west Africa, versus 1 in every 40 ha cultivated in central Africa.

Energy

Energy use at the household level is relatively minor. There are energy costs embedded in the manufacture and distribution of the agrochemical inputs used by tree crop farmers. However, energy use in the production of most tree crops is relatively low as powered machinery is not widely used. There is an energy component in marketing.

Given the current small energy requirements in the production and farm gate marketing costs of tree crop farming systems, the volatility in energy prices has not greatly affected the profitability of tree crop farming in sub-Saharan Africa. As outlined earlier, palm oil markets include the growing global demand for bioenergy.

Human capital, knowledge sharing and gender

As earlier, smallholder education levels are low and access to resources is limited. Public sector extension services in west and central Africa have not been successful in transferring knowledge to smallholders. In an analysis of pineapple targeted for European markets and produced intensively in the eastern region of Ghana, Conley and Udry (2010) found no impact of formal extension contact on the diffusion of fertilizer use technologies. The study did find evidence that learning through farmer-to-farmer information networks, based on farmer experimentation, had a major influence on the producer's practices. Farmer field schools (FFS) represent a more costly extension tool, which incorporates elements of adult education and farmer experimentation to strengthen the analytical capacity of farmers. The recently completed Sustainable Tree Crops Program developed FFS curricula for integrated pest and disease management, integrated soil fertility management, post-harvest management and planting/replanting practices of cocoa tree crop systems and a planting/replanting curriculum for oil palm cropping systems (David et al. 2007). Unfortunately such approaches have not been financially sustainable.

Some tree farmers are increasing capacity by employing workers who have gained skills and experience in industrial plantations. However, the underdevelopment of human capital in IPS plantation management and agronomy has constrained the growth of this particular farming subsystem. Skills are needed in a range of areas including best practice plantation management, finance and computer technology.

Male dominance of the tree crop farming system is reflected in Table 9.11, which shows over 93 per cent of cocoa farms under male ownership. The introduction of tree crop farming has mobilized male surplus labour, but it has also increased women's workload, as demonstrated earlier for the cocoa-based FRS.

Tree crop farmers have rapidly taken up the use of mobile telephones, and SMS-based networks for extension and market information are evolving rapidly. Another important

Table 9.11 Land ownership by mode of acquisition and gender, in the cocoa belt of West and Central Africa

<i>Mode of acquisition</i>	<i>Men</i>	<i>Women</i>	<i>Subtotals</i>
Inherited	5,606	408	6,014
Purchased	2,311	167	2,478
Other	217	12	229
Subtotals	8,134	587	8,721

Source: IITA (2002).

innovation since the late 2000s has been the introduction of low-cost motorcycles from Asia. Motorcycle taxi services have rapidly evolved in many rural areas and have significantly lowered the costs of communications, which facilitates knowledge-sharing between households and state extension agents.

Farming system performance

Most smallholder farming systems have multiple objectives which include profitability (gross revenue less purchased inputs less opportunity cost of household labour input), investment in children's education, food security (household consumption of own production and purchase of food staples), tenured access to land, land productivity (crop yield) and sustainability issues.

As outlined earlier, fertilizer use is absent to low in the FRS subsystem and higher in the more intensified SIS and IPS subsystems, but constrained by cost and lack of availability. The use of hybrid seed is low, despite evidence that selected hybrid varieties developed by the Cocoa Research Institute of Ghana (CRIG) are four times as productive as local unimproved material (Gockowski 2012). The lack of availability of hybrid seed pods in April and May is a major constraint to their wider adoption. Currently, hybrid pods are distributed in November and December, which is the height of the cocoa harvest and also the start of the dry season. At this busy time of the year most farmers are unable to devote the time and effort required to nurse hybrid cocoa seedlings until April/May when food crop and tree crop planting occurs. If hand pollination of cocoa flowers were scheduled so that the harvest of ripe pods were to occur coincident with the April-May planting season, then farmers could plant hybrid cocoa seed at stake as is their current practice with unimproved farmer selections. Further improving farmer access to hybrid pods by reducing the distance travelled and transaction costs of acquiring hybrid pods would also help to increase adoption.

Another important determinant of productivity in the tree crop farming system is tree age. Most perennial tree crops show an 'inverted U' yield-age profile. Yield remains at zero the first few years after planting, then begins climbing until finally reaching a plateau as the tree reaches maturity, and then eventually declines as senescence, pests, disease and nutrient depletion manifest themselves (Ahenkorah et al. 1987). Figure 9.12 illustrates an empirical yield-age distribution from Ghana.

Annual costs and returns per hectare developed for representative cocoa FRS and SIS using Ghana field data indicate strong financial incentives for adopting intensified subsystems, with yields and income more than double the FRS (Table 9.12). Even with the fertilizer subsidy removed the SIS still outperforms the FRS by 370 Ghana cedi (GHc) ha⁻¹, although at this point the producers' cash outlay rises to nearly 600 GHc ha⁻¹, which is a lot of cash for a smallholder especially when rural financial markets do not function well.

Table 9.13 presents yields of FRS cocoa per hectare and yields per household member across farm size quintiles. This clearly illustrates declining land productivity as farm size increases, while labour productivity per household member increases. Overall, yields are very low relative to potential yields, reflecting limited technological innovation and the continued mining of nutrient stocks.

Higher land yields among smaller producers are the result of a higher input of family labour on a per hectare basis. The relatively low yield per household member for the smallest quintile of producers suggests that even at a farm gate price of US\$2/kg, returns are not likely to exceed the World Bank poverty measure of US\$1.25 per capita per day for many in the distribution.

Figure 9.12 Yield-age profile of cocoa tree stocks in the Bia district of western Ghana (n=172).

Source: IITA (2011).

Table 9.12 Costs and returns per hectare for cocoa FRS and SIS enterprises based on 2009 prices

Item description	Unit	Price GHc	Forest rent		Smallholder intensified	
			Qty	Subtotal	Qty	Subtotal
Cocoa	Kg	2.2	288	636	650	1435
Fertilizer	Kg	0.5	0.0	0	225	112
Fungicide	Sachet	1.1	34	37	23	25
Insecticide	Litre	16.8	1.1	19	2.5	42
Herbicide	Litre	7.6	0.2	1	1.1	8.2
Hired labour	Worker	400	0.2	90	0.4	147
Family labour	Worker		0.5	0	0.5	0.0
Capital depreciation	GHc			11		23
Total cost	GHc			158		357
Net return	GHc			478		1079

US\$1 = 1.29 GH cedi (2009).

Source: Author's calculation.

Smallholder adoption of commercial oil palm production, as opposed to the tending of self-seeded wild groves of oil palm, is a relatively recent phenomenon in the economic history of west Africa. In fact, most of the growth in oil palm production over the last 20 years has occurred in the smallholder sector. Ntsiful (2010) did a comparative

Table 9.13 Partial productivity measures for cocoa producers across west Africa, for five categories (I to V) of cocoa productive area per household

Quintile	Yield per ha	Yield per HH member	HH members per producing ha	Output per HH	Share of producing area	Share of total output
	kg	kg		kg	%	%
I	415	69.8	5.9	548	4	7
II	357	87.3	4.1	918	9	12
III	323	123	2.6	1,267	13	17
IV	272	148	1.8	1,657	21	22
V	210	236	0.9	3,259	53	43
Grand total	260	143	1.8	1,530	100	100

Source: IITA 2002; see Table 9.8 for definition of the farm size (quintile) categories.

multidimensional poverty analysis of contractually obligated outgrowers, independent oil palm growers and non-oil palm producing rural households in two regions of Ghana. His main findings were that outgrowers: (1) exceeded the incomes of independent growers by threefold and non-oil palm producers (principally maize-growing) by fivefold; (2) consumed more fruits, vegetables, meat, eggs and dairy products; (3) had better accommodation and were more likely to have electricity and running water in the household; (4) were more likely to have bank accounts and access to credit; (5) had more material assets such as refrigerators, televisions and mobile phones; and (6) made substantially higher investments in their children's education than the other households.

The conclusion of the study was that the outgrower contract farming model was an effective tool for poverty alleviation in rural areas. This corroborates well with the South East Asian experience where the growth of the palm oil sector has had an enormous impact on poverty reduction. World Growth (2011) cites poverty reduction of 6 million persons from palm oil production in Indonesia. Indeed, the spectacular rise of the oil palm industry in Malaysia and Indonesia has been one of the most noteworthy achievements in poverty reduction by agricultural science to date.

Social values and environmental performance of the subsystems are also relevant. Phalan et al. (2011) comprehensively measured income and biodiversity conservation for land use systems in what was formerly the high forest region of southern Ghana, and concluded that more biodiversity would be conserved through the pursuit of land-sparing, high-yielding technologies such as the SIS as compared to land sharing FRS type systems as described earlier. Although relatively high levels of biodiversity are maintained by the cocoa FRS, the average yields are low (Jagoret et al. 2011). Several types of cocoa and oil palm subsystems were evaluated; in regions where access to fruit and forest product urban markets was good, shaded cocoa agroforests had the highest income, environmental and biodiversity values (Gockowski et al. 2005). However, this win-win outcome was contingent upon urban market access for the secondary products produced by these agroforests. When markets are not accessible the income performance of these 'land sharing' multi-strata subsystems declines significantly. Low rates of land use productivity in the FRS have had disastrous consequences on the west African Guinea rainforest (Gockowski and Sonwa 2011). Resolving the debate requires empirical investigation of these trade-offs.

Strategic priorities for the system

A ranking of poverty escape pathways for populations in the tree crop farming system regions of west and central Africa must begin with the question of who are the chronic poor in these systems and how do they currently earn their livelihoods? All evidence points to a landless or near landless class of migrants working as sharecroppers for the extensive FRS tree crop subsystem. The fact that a one-third share of an FRS tree crop system – representing a few hundred dollars – provides an incentive for migration speaks to their impoverishment. They have little capacity for intensification or diversification, cannot increase farm size and often have never been to school. Improving their livelihoods depends first and foremost on expanding opportunities within the unskilled agricultural labour market (Table 9.14).

Direct investment in industrial plantation subsystems are estimated to create anywhere from 10 to 20 jobs per square kilometre of plantation development. In many underdeveloped regions that is more jobs than there are rural inhabitants. As an example, the Cameroon Development Corporation employs over 18,000 permanent workers and nearly 1,000 supervisors and managers on an area of 420 km² – a density of about 45 jobs/km². Today Malaysia and Indonesia stand at the top of the multibillion-dollar palm oil industry and have witnessed unprecedented and largely unrecognized reduction in rural poverty because of this growth.

While the formal jobs generated by the industrial oil palm plantations account for the largest share of South East Asian poverty reduction, the growth of the smallholder palm oil sector has also contributed to poverty reduction. Smallholders account for over one third of the total area of planted oil palm in Malaysia and Indonesia and as much as 33 per cent of the output. Elsewhere, as in West African countries that produce mainly for domestic and regional markets, smallholders produce up to 90 per cent of the annual harvest.

The IPS outgrower schemes are another form of contractual engagement with smallholders, which link them to global markets through the marketing and processing infrastructure of the IPS. Smallholders are able to access inputs and knowledge which allows them to transform their FRS tree crop systems into more sustainable intensified production systems.

Through investment in plant breeding and agronomic research, Malaysian and Indonesian science have developed the world's most productive oilseed production system. Investments in these systems have resulted in the conversion of 13 million ha of South East Asian tropical forest, which is a substantial environmental cost. Against this cost, policy makers must weigh the benefits from eliminating rural poverty.

Other hotspots of chronic poverty within the tree crop farming system domain include the more remote areas bordering the forest-based farming system, where land is still relatively abundant but difficulties in getting goods to markets presents a heavy tax on production. These regions are enticing for IPS investment because land is still abundant and labour is also available. Some communities in such areas are negotiating long-term leases with industrial plantation entities for a portion of their lands. In exchange, the community receives: (1) access to new production technology through smallholder outgrower schemes; (2) access to new markets through investments in processing and transport capacity; and (3) social infrastructure such as schools and clinics help to develop human capital.

With suitable land increasingly scarce in South East Asia, many large corporations are looking to develop tree crop plantations in west and central Africa. The Congo Basin has over 179 million ha of extant tropical forests, while over 50 per cent of its population

Table 9.14 Relative importance of household livelihood improvement strategies

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total ag pop	—	40	60	100
Intensification	4	1	6	4
Diversification	1.5	1	1	1
Increased farm size	1.5	0	1	0.5
Off-farm income	2	8	1	4
Exit from agriculture	1	0	1	0.5

Sources: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

lives in abject poverty. African leaders need to consider the responsible development of a portion of its still immense stock of forest in order to provide jobs for the poor.

Tree crop producers have more scope to generate positive growth from their existing assets. Much can be learned from Ghana's policy-induced episode of intensification that is pertinent for broad-based growth. How can state interventions in input markets build on the existing private sector institutions and infrastructure? What were the institutional successes and failures of the programme? What were the linkages between input supply and credit that permitted broad-based adoption of yield-augmenting fertilizers? Achieving the transformation will require a broad range of interventions and investments to address strategic constraints and to capitalize on emerging opportunities.

The principal constraints are:

- the lack of a shared vision and strategic framework for the sustainable intensification of agriculture among policymakers, private investors, research managers, extension services, consumers and most importantly farmers and their organizations over all sectors and farming systems
- underinvestment in human capital
- underdeveloped rural markets (credit, input and outputs)
- gross underinvestment in both applied and basic research, which are prerequisites for effective extension
- a lack of modern port facilities, roads and rail infrastructure, especially in central Africa.

The principal emerging opportunities include:

- increased financial flows from IPS subsystems and affiliated outgrower schemes
- penetration and investment into African markets by large multinational agricultural commodity enterprises
- steady growth in global demand for tree crops
- global certification of production standards
- rapid uptake of mobile phone technology among the rural population.

Multinational agricultural commodity firms with interests in cocoa, oil palm, tropical timber and coffee have recently invested in sustainability certification schemes with groups of African smallholders. Avoiding irreversible soil impoverishment is a necessary condition

for system sustainability. Multinational-backed cocoa buyers are providing inputs on credit using the farmer's standing crop as collateral. Greater formalization of these institutions is an important first step in the development of rural financial markets. The recent wave of foreign investment in IPS subsystems presents both an opportunity and a threat. The share of physical capital in smallholder African agriculture is extremely low. The capacity of a large-scale multinational to invest millions in essential capital goods such as oil milling plants can instantly create a market where none existed prior to the investment. There is a threat, however, that an enclave sector develops with little benefit to local communities (Cotula et al. 2009).

Crosscutting priorities: research, extension, public infrastructure, land tenure reform

In recent years, private capital markets have shown a renewed interest in African agriculture. Unfortunately the essential public investments needed to support a modern science-based agricultural sector are less evident. High-priced commodity markets are signalling to farmers and their governments that now is the time to innovate, invest and increase agricultural productivity.

The first priority for government investment is to revitalize the capacity of agricultural science after many years of neglect. The situation has not changed since Ruttan and Thirtle's (1989) study of technological and institutional change in African agriculture expressed concern over Africa's underinvestment in the human capital needed to invent, diffuse and effectively deploy new agricultural technology. Increasing investments in rural education, research and extension remain critical priorities for the sustainable intensification of farming systems in the humid tropics.

R&D must address three main areas of need: (1) the development and introduction of improved planting materials and their delivery systems adapted to farmer planting preferences; (2) integrated soil fertility management practices tailored to local agroecological and socioeconomic situations; and (3) integrated pest and disease management. There is a trove of research knowledge on cocoa, rubber, coffee, citrus and particularly oil palm in the commodity research institutes of the pan-tropics, including the Rubber Research Institute of Sri Lanka, the Indonesian Oil Palm Research Institute, the Malaysian Palm Oil Board and the Cocoa Research Institute of Ghana. Developed country research institutes such as Penn State, Centre de coopération internationale en recherche agronomique pour le développement (CIRAD) and the United States Department of Agriculture (USDA) are working on molecular approaches with African partners to speed up the process of tree crop genetic improvement. Any new investment in R&D should build on this foundation of knowledge.

While a lot of lost ground can be made up quickly through south-south research collaborations and through the encouragement of foreign investment, a good portion of productivity growth is location and system specific and will require substantial investment to develop local research capacity for innovation.

A knowledge-based agricultural sector will also require substantial investments in the human capital employed in the agricultural sector, whether as managers of intensified smallholder tree crop farming systems, or as managers of 5000 ha oil palm plantations. This will require investments in education as well as public health.

The development of well-trained managers versed in the best management practices for plantations and estate outgrower projects will encourage the foreign direct investment needed to create additional jobs and generate public revenues through taxation.

Beyond skills in plantation management and agronomy, successful managers must also have knowledge of geographical information systems, financial management systems, environmental best practices and community development approaches.

Agriculture has become one of the most globalized trade sectors, with high reward for marketing efficiency. In today's global economy, public investments in port and transport facilities are important for encouraging the private investments needed for transformational growth.

The costs of marketing commodities in Africa are excessively high and are a constraint to growth. One of the keys to sustainable agricultural intensification is the development of a viable private sector input supply sector. Smallholder intensification induced by the policies of the Ghana Cocoa Marketing Board achieved remarkable accomplishments and demonstrated the willingness of smallholders to adopt new technology when it works and improves their livelihoods. But despite all the indisputable achievements, it is not yet clear whether the foundations have been laid for a viable and competitive input supply sector.

One question is the role of input subsidies. An argument is sometimes made that fertilizer and pesticide subsidies, although distorting efficient market outcomes, are necessary to 'prime the pump' for adoption by smallholders. Others argue in support of fertilizer subsidies as a correction to the failure of markets to reflect all of the environmental costs of not using external soil amendments (Gockowski and Sonwa 2011). The main argument against the use of subsidies is that they are costly and detract from other, more essential, public investments. Another critique against the use of subsidies is that poorly designed programmes can threaten the emergence of a private input supply sector, particularly when a state agency is employed in their distribution. Finally, the non-participation of the poor and landless in these programmes is a common result. In fact, if the cost of such programmes is netted out of the price paid to producers, as is the case in Ghana, input subsidies can actually make non-adopters worse off (Gockowski 2012). The history of commodity-based input subsidy programmes is not replete with success stories. Ideally a responsive input supply sector would be able to meet the demands and supply the needs of the whole range of production possibilities from tree crops to food crops. This would allow for more rapid adjustment to market fluctuations and increase the propensity for diversification.

Farmer extension is another important public good that has habitually been underfunded. New communication technologies present a potentially revolutionizing means of delivering knowledge to smallholders as well as receiving knowledge from farmers. Extension services need to reconsider the village-based extension agent model and incorporate new information technology approaches.

One of the criticisms made of the green revolution was that large landowners benefited much more than small landowners and landless workers (Hayami and Ruttan 1985). Agriculture is a competitive business. Over time, the efficient farmers tend to accumulate productive resources while the inefficient are forced eventually to either seek alternative production enterprises in which they are more competitive, or to exit agriculture and search for alternative livelihoods. The important issue is to make technology accessible to small and large producer alike. If the technology tends to be land saving and labour using (as most biological and chemical innovations are), then that technology is likely to support the gradual transformation of small family farms (Hayami and Ruttan 1985). Land tenure institutions that allow equitable redistribution of land assets, and well-developed credit markets, are required to facilitate broad-based and equitable participation in growth-oriented technical change. Customary land tenure and inheritance institutions in Africa

can be a constraint to economic development as they may, over time, lead to excessively small farm sizes to the point that farming becomes just a part-time occupation for the majority of households, as has happened in south-eastern Nigeria. However, the statutory land laws inherited from colonial times have not proven effective in dealing with an excessive number of land disputes. Efforts to combine customary and statutory law are showing some promise.

More knowledge is needed about the magnitude and type of climate change likely for west Africa in order to design adaptive measures. There is a pressing need to rebuild the climate monitoring network in Africa, linking the weather stations to global reporting networks and integrating with satellite observations. Tree crop production systems have been proposed as potential carbon sinks when targeted at already deforested land (Jagoret et al. 2012). Rapid advances in remote sensing of land use change offer the potential for a globally consistent means of monitoring land use change at a spatial resolution with relevance to local communities (Hansen et al. 2013).

System conclusions

The drivers of change affecting the intensification of tree crop farming system of Africa should interest opinion leaders, decision makers, business leaders and stakeholders seeking to transform the smallholder agricultural sector and improve its associated livelihoods. Transforming from traditional low-input low-output farming systems to intensified knowledge-based systems is among the chief aims of the African Union as expressed in the Malabo Declaration on Accelerated Agricultural Growth and Transformation (African Union 2014). Rural transformation should also interest environmental planners and conservationists looking to stem the rates of deforestation and forest degradation associated with extensive agriculture.

Evidence has been presented to suggest that sustainable agricultural intensification will be fundamental to achieving development goals regarding poverty, economic growth and the environment. Africa failed to capitalize on the development of palm oil as the pre-eminent vegetable oil in global trade. Capital investors now wish to bring the South East Asian model of oil palm development back to Africa, presenting an opportunity to capture market share in this rapidly growing US\$45 billion industry. The impact of doing so could be transformational, and African opinion leaders are calling for it to happen (Ayodele 2010).

Note

- 1 Rainforest was defined as having an average canopy height of 35 to 40 m and a canopy coverage of more than 70 per cent.

References

- African Union (2014) The Maputo declaration on accelerated agricultural growth and transformation for shared prosperity and improved livelihoods. Twenty-third ordinary session of the AU assembly in Malabo, Equatorial Guinea, 26–27 June 2014, <https://au.int/en/documents/20150617-2>.
- Ahenkorah, Y., Halm, B.J., Appiah, M.R., Akrofi, G.S. and Yirenkyi, J.E.K. (1987) 'Twenty years results from a shade and fertiliser trial on Amazon cocoa (*Theobroma cacao*) in Ghana', *Experimental Agriculture*, vol. 23, pp. 31–39.

- Akiyama, T. and Trivedi, P.K. (1987) 'Vintage production approach to perennial crop supply: An application to tea in major producing countries', *Journal of Econometrics*, vol. 36, nos. 1–2, pp. 133–161.
- Asare, R. (2011) Cocoa seed multiplication: an assessment of seed gardens in Cameroon, Ghana and Nigeria. *Sustainable Tree Crops Program Working Paper No. 11*, Ibadan, Nigeria.
- Ayodele, T. (2010) 'The World Bank's palm oil mistake', *The New York Times*, 15 October 2010. Op-Ed contribution.
- Bazzi-Veil, L. and Kambou, S. (2002) *Etude communautaire sur le travail des enfants dans les plantations cacaoyères en Côte d'Ivoire*. Centre d'Etudes Prospectives et Appliquées sur les Politiques Sociales et les Systèmes de Sécurité Sociale (CEPRASS), IITA, ILO-IPEC, Abidjan/Ibadan www.iita.org/c/document_library/get_file?p_l_id=98899&folderId=104025&name=DLFE-1147.pdf.
- Benjamin, D. and Deaton, A. (1993) 'Household welfare and the pricing of coffee and cocoa in Côte d'Ivoire: Lessons from the Living Standards Survey', *World Bank Economic Review*, vol. 7, no. 3, pp. 293–318.
- Berry, S. (1988) 'Property rights and rural resource management: The case of tree crops in West Africa', *Cahiers des Sciences Humaines*, vol. 24, no. 1, pp. 3–18.
- Blocher, J. (2006) 'Building on custom: Land tenure policy and economic development in Ghana', *Yale Human Rights & Development Law Journal*, vol. 9, pp. 166–202.
- Boserup, E. (2007) *Woman's Role in Economic Development*. Earthscan.
- Cheyens, E. and Rafflegeau, S. (2005) 'Family agriculture and the sustainable development issue: possible approaches from the African oil palm sector. The example of Ivory Coast and Cameroon', *Oléagineux, Corps Gras, Lipides*, vol. 12, no. 2, pp. 111–120.
- Conley, T.G. and Udry, C.R. (2010) 'Learning about a new technology: Pineapple in Ghana', *American Economic Review*, vol. 100, no. 1, pp. 35–69.
- Cotula, L., Vermeulen, S., Leonard, R. and Keeley, J. (2009) *Land Grab or Development Opportunity? Agricultural Investment and International Land Deals in Africa*. IIED/FAO/IFAD.
- David, S. Agordorku, S. Bassanaga, S., Couloud, J.-I., Kumi, M.A., Okuku, I. and Wandji, D. (2006) A guide for conducting farmer field schools on cocoa integrated crop and pest management. International Institute of Tropical Agriculture. Accra, Ghana, www.share4dev.info/ffsnet/documents/3184.pdf.
- Deaton, A. (1999) 'Commodity prices and growth in Africa', *Journal of Economic Perspectives*, vol. 13, no. 3, pp. 23–40.
- Edwin, J. and Masters, W.A. (2005) 'Genetic improvement and cocoa yields in Ghana', *Experimental Agriculture*, vol. 41, pp. 491–503.
- FAOSTAT (2015) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- Gerasimchuk, I. and Koh, P.Y. (2013) *The EU Biofuel Policy and Palm Oil: Cutting Subsidies or Cutting Rainforest?* International Institute of Sustainable Development.
- Ghana Statistical Service (2009) *Ghana Demographic and Health Survey 2008*.
- Gilbert, C.L. and Varangis, P. (2003) 'Globalization and international commodity trade with specific reference to the West African cocoa producers', in R.E. Baldwin and L.A. Winters (eds) *Challenges to Globalization: Analyzing the Economics*. University of Chicago Press.
- Gockowski, J. (2012) *Policy Led Intensification and Returns to Input Use in Ghana*. International Institute of Tropical Agriculture, Accra, Ghana.
- Gockowski, J., Afari-Sefa, V., Sarpong, D.B., Osei-Asare, Y. and Agyeman, N.F. (2013) 'Improving the productivity and income of Ghanaian cocoa farmers while maintaining environmental services: What role for certification?' *International Journal of Agricultural Sustainability*, vol. 11, no. 4, pp. 331–346.
- Gockowski, J., Robiglio, V., Muilerman, S. and Agyeman, N.F. (2011) *Agricultural Intensification as a Strategy for Climate Mitigation in Ghana*. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
- Gockowski, J. and Sonwa, D. (2011) 'Cocoa intensification scenarios and their predicted impact on CO2 emissions, biodiversity conservation, and rural livelihoods in the Guinea rain forest of West Africa', *Environmental Management*, vol. 48, no. 2, pp. 307–321.

- Gockowski, J., Tchatat, M., Dondjang, J., Hietet, G. and Fouda, T. (2010). 'An empirical analysis of the biodiversity and economic returns to cocoa agroforests in southern Cameroon', *Journal of Sustainable Forestry*, vol. 29, nos. 6–7, pp. 638–670.
- Gockowski, J., Tonye, J., Diaw, C., Hauser, S., Kotto-Same, J., Moukam, A., Nomgang, R., Nwaga, D., Tiki-Manga, T., Tondoh, J., Tchoundjeu, Z., Weise, S. and Zapfack, L. (2005) 'The forest margins of Cameroon', in C.A. Palm, S.A. Vosti, P.A. Sanchez and P. Ericksen (eds) *Slash and Burn: The Search for Alternatives*. Columbia University Press.
- Gockowski, J., Yapo, R., Okafor, C., Mva, J. and Gyamfi, I. (2008) Institutional innovation in the credit, input and cocoa markets of west Africa. *STCP Working Paper*, no 8, International Institute of Tropical Agriculture.
- Guyer, J. (1984) 'Family and Farm in Southern Cameroon', *African Research Studies* No. 15, African Studies Center, Boston University.
- Hansen, M., Potapov, P., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., Thau, D., Stehman, S., Goetz, S., Loveland, J., Kommareddy, A., Egorov, A., Chini, L., Justice, C. and Townshend, J. (2013) 'High-resolution global maps of 21st-century forest cover change', *Science*, vol. 342, no. 6160, pp. 850–853.
- Hayami, Y. and Ruttan, V. (1985) *Agricultural Development: An International Perspective*. The Johns Hopkins Press, second edition.
- Hicks, J. R. (1932) *The Theory of Wages*. Macmillan.
- Hill, P. (1963) *The Migrant Cocoa Farmers of Southern Ghana: A Study in Rural Capitalism*. Cambridge University Press.
- ICCO. (2015) *Quarterly Bulletin of Cocoa Statistics*, Vol. 41, No. 4, Cocoa Year 2014/15.
- IITA. (2002) *Sustainable Tree Crop Program Baseline Survey Data for the Cocoa Subsectors of Côte d'Ivoire, Ghana, Nigeria and Cameroon*. International Institute of Tropical Agriculture, Ibadan, Nigeria.
- IITA. (2011) *Sustainable Tree Crop Program Survey Data for the Smallholder Intensified Farming Subsystem in Bia District Ghana*. International Institute of Tropical Agriculture, Ibadan, Nigeria.
- IMF. (2015) *International Monetary Fund Primary Commodity Prices*, www.imf.org/external/np/res/commod/index.aspx.
- Jagoret, P., Michel-Dounias, I. and Malézieux, E. (2011) 'Long-term dynamics of cocoa agroforests: a case study in central Cameroon', *Agroforestry Systems*, vol. 81, no. 3, pp. 267–278.
- Jagoret, P., Michel-Dounias, I., Snoeck, D., Ngnogué, H.T. and Malézieux, E. (2012) 'Afforestation of savannah with cocoa agroforestry systems: a small-farmer innovation in central Cameroon', *Agroforestry Systems*, vol. 86, no. 3, pp. 493–504.
- Kolavalli, S. and Vigneri, M. (2011) 'Cocoa in Ghana: shaping the success of an economy', in P. Chuhan-Pole and M. Angwafo (eds) *Yes Africa Can: Success Stories from a Dynamic Continent*. World Bank.
- Mayaux, P., Pekel, J.-F., Desclée, B., Donnay, F., Lupi, A., Achard, F., Clerici, M., Bodart, C., Brink, A., Nasi, R. and Belward, A. (2013) 'State and evolution of the African rainforests between 1990 and 2010', *Philosophical Transactions of the Royal Society B*; DOI: 10.1098/rstb.2012.0300.
- Norris, K., Asase, A., Collen, B., Gockowski, J., Mason, J., Phalan, B. and Wade, A. (2010) 'Biodiversity in a forest-agricultural mosaic – the changing face of West African rainforests', *Biological Conservation*, vol. 143, pp. 2341–2350.
- Ntsiful, A.K. (2010) Outgrower oil palm plantations scheme by private companies and poverty reduction in Ghana. PhD thesis, St. Clements University, Turks and Caicos Islands.
- Phalan, B., Onial, M., Balmford, A. and Green, R.E. (2011) 'Reconciling food production and biodiversity conservation: land sharing and land sparing compared', *Science*, vol. 333, no. 6047, pp. 1289–1291.
- Ruf, F. (1995) *Booms et Crises du Cacao: Les Vertiges de l'Or Brun*. CIRAD-SAR Ministère de la coopération.

- Ruf, F. (2008) *Developing Smallholder Rubber Production: Lessons from AFD's Experience*. Ivory Coast report, Agence Française de Développement.
- Ruttan, V. and Thirtle, C. (1989) 'Induced technological change in African agriculture', *Journal of International Development*, vol. 1 no. 1, pp. 1–45.
- Sanchez, P.A., Sheperd, K., Soule, M., Place, F., Buresh, R., Izac, A-M., Mokwunye, U., Kwesiga, F., Ndiritu, C. and Woomer P. (1997) 'Soil fertility replenishment in Africa: An investment in natural resource capital', in R. Buresh, P. Sanchez and F. Calhoun (eds) *Replenishing Soil Fertility in Africa*. SSSA special publication number 51. Soil Science Society of America.
- Sheil, D., Casson, A., Meijaard, E., van Noordwijk, M., Gaskell, J., Sunderland-Groves, J., Wertz, K. and Kanninen, M. (2009) The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know? Occasional paper no. 51. CIFOR, Bogor, Indonesia.
- Simpson, D.H. (1937) *Gold Coast Men of Affairs*. Colonial History Series, Dawsons of Pall Mall, London.
- Stoorvogel, J.J. and Smaling, E.M.A. (1990) *Assessment of Soil Nutrient Depletion in Sub-Saharan Africa: 1983–2000*. Winand Staring Centre, Wageningen.
- USDA (2013) Oilseeds: World markets and trade. <https://downloads.usda.library.cornell.edu/usda-esmis/files/tx31qh68h/d791sg56p/2801pg691/oilseed-trade-12-10-2014.pdf>
- Vermeulen, S. and Goad, N. (2006) *Towards Better Practice in Smallholder Palm Oil Production*. Natural Resource Issues Series No 5, International Institute for Environment and Development.
- World Growth (2011) *The Economic Benefit of Palm Oil to Indonesia*. Palm Oil Green Development Campaign report. http://worldgrowth.org/site/wp-content/uploads/2012/06/WG_Indonesian_Palm_Oil_Benefits_Report-2_11.pdf.

10 The pastoral farming system

Balancing between tradition and transition

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Key messages

- The African pastoral farming system consists of livestock and drylands crop-based production that supports an agricultural population of 38 million people of whom 13.4 million in sub-Saharan Africa are extremely poor.
- Human population growth has resulted in low per capita livestock and land resources, and while the farming system has options to develop agriculture, further demographic expansion will exacerbate degradation and inequality.
- While there is potential for agricultural development, e.g. through intensification and greater market orientation, such development needs to take into account pastoral peoples' access rights to resources and minimize trade-offs with current land and water users.
- Effective drought management, a key to the success of pastoralism, relies on multiple resource management strategies and community interactions. Therefore, there is a need for policies that strengthen the resilience of agriculture and pastoralists livelihoods through, e.g. support to livestock mobility, agricultural insurance, sustainable land and water management as well as monetary and legal support for effective implementation.
- Interventions that strengthen opportunities for a future outside agriculture, such as education and job creation, are needed for those living in chronic poverty.

Summary

This chapter reviews the performance of the pastoral farming system in Africa in terms of productivity, sustainability and human development outcomes. The chapter identifies strategic priorities to reduce by half, by 2025, the number of people living below the poverty line in pastoral farming system. While the pastoral farming system performs well in terms of productivity per unit area of land, economic sustainability is complicated by rapid population growth progressively reducing the livestock resource base per capita, and the system performs poorly in terms of human development outcomes such as poverty, education and health. The two most promising poverty escape pathways are intensification of the farming system through greater market orientation, secure access to natural resources and to supplemental feeds, and second, an exit from agriculture through education and development of alternatives for the young and pastoral dropouts. Other less prospective options are diversification of the farming system and obtaining off-farm income.

Overall description of the pastoral farming system

The pastoral farming system occupies 4.88 million km², with close to 30 per cent each in the Sahel, eastern and southern Africa and 16 per cent in northern Africa. Some 77 million people inhabit the system (average population density 15.77 persons per km²). Of these 77 million, 38 million people (49.4 per cent) are involved in agriculture.¹ The system contains a livestock population equivalent to 42 tropical livestock units (TLU).² This represents an average livestock density of 0.09 TLU/ha and an average holding of 0.90 TLU/person in agriculture. There is 330,000 km² (7 per cent of total land) under crop cultivation and 11,000 km² (0.2 per cent of total land) under irrigation (Table 10.1).

The word pastoralism originates from *pastor* or herder, and pastoral production revolves around herdsmen, mobile livestock and rangelands. In this chapter the pastoral farming system is defined as a land system with an average length of growing period (LGP) between 30 and 90 days (Figure 10.1). In the Sahel and eastern Africa more than 50 per cent of household income is generated from mobile livestock production (Swift 1988).

Figure 10.1 The pastoral farming system and subsystems.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Table 10.1 Basic system data (2015): pastoral farming system

<i>Item</i>	<i>Data</i>
Total human population (million)	77
Agricultural population (million)	38
Total area (million ha)	488
Cultivated area (million ha; % of total area)	33; 7
Irrigated area (million ha; % of cultivated area)	1.1; 3
Total livestock population (million TLU)	42
Major agroecological zone	Tropical warm arid
Length of growing period (average, days; core range, days)	59; 30–90
Access to services (low/medium/high)	Low
Distance to 50k market (average, hr; core range, hr)	8.3; 4–10+
Agricultural population density (persons/total area; persons/cultivated area)	0.1; 1.2
Livestock density (TLU/total area; TLU/cultivated area)	0.09; 1.3
Standard farm and herd size (cultivated area/household; TLU/household)	4.7; 6.0
Extreme poverty (% of rural population)	40*

Source: Refer to Table 2.4.

*for sub-Saharan Africa only.

In contrast, the pastoral farming system in southern Africa is dominated by ranch-based livestock production.

The Sahelian, the northern and the southern African subsystems experience unimodal rainfall, while bimodality prevails in eastern Africa (Vrieling et al. 2013). Forage production is affected by this seasonality and inter-annual variation in precipitation, including cycles related to the El Niño Southern Oscillation (ENSO), with drier years associated with El Niño and La Niña events in southern and eastern Africa respectively, while rainfall in north and western Africa associates with the North Atlantic Oscillation. While rainfall declined and then recovered in the Sahel, trends were smaller or absent in the northern, eastern and southern African subsystems.

The three sub-Saharan subsystems are of equivalent size, but differ in human population and livestock density. The southern African subsystem has lower human (4.23 people per km²) and livestock (0.0565 TLU per km²) population densities than the Sahel (16.14 and 0.162) and eastern Africa (17.34 and 0.0903). The area under crop cultivation is low in all three subsystems, but is expanding in the southern Sahelian subsystem. Income poverty is widespread in all three subsystems, but the per capita livestock wealth is greater in southern Africa (1.50 TLU) than in the eastern (0.61 TLU) and Sahelian (0.97 TLU) subsystems.

During the wet season, high forage digestibility and high protein concentrations allow livestock herds to grow. Dry season forage and water shortages force herders to move herds, seeking water and fodder and herd survival elsewhere (Ayantunde et al. 2011). The subsystems differ in livestock mobility. Migration in the Sahel involves a regular, annual, long distance movement with ad hoc displacement during drought. In eastern Africa, migration involves short regular seasonal movement with ad hoc longer distance movements during drought, while migration occurs over shorter distances in northern Africa.

The Sahelian subsystem, extending from Senegal to Sudan, is characterized by the annual transhumance to the agropastoral and the cereal-root crop mixed farming systems in the south (Figure 10.2). The transhumance northward (Box 10.1) benefits from the high fodder quality in the Sahel, which spans hundreds of kilometres and lasts up to eight months (Ayantunde et al. 2010). Today, many pastoralists have settled and grow crops in the southern pastoral and the northern agropastoral system (Chapter 4 this volume).

Box 10.1 Transhumance in the Sahel

Transhumance is a seasonal north-south movement between wet season pastures in the Sahel and the agropastoral and cereal-root crop mixed farming systems to the south (Figure 10.2) where livestock resides in the dry season (Toure et al. 2012). This migration spanning hundreds of kilometres lasts from three to eight months. Transhumant pastoralism contributes significantly to West African livestock production and involves 70–90 per cent of the Sahel's cattle, while transhumant sheep comprise 30–40 per cent of its small ruminants. During the dry season, most pastoralists graze their herds on the croplands in more humid farming systems to the south, generally on the lands of their families while a minority interacts with non-related agricultural communities. The benefits to pastoralists include herd productivity from grazing crop stubble left after harvest, reduction in herd mortality and production costs, and building social relations with host communities. To the host community, the benefits of transhumance include manuring of crop fields, availability of milk, and obtaining young animals for traction, dairy production and fattening. Despite these benefits, there is increasing conflict between transhumant herders and crop farmers because of damage to crops, increased competition for shrinking rangeland and fodder resources, and increased livestock production by resident populations (Turner et al. 2011).

In eastern Africa, pastoral livestock production does not include annual migration into more humid farming systems. With its bimodal rainfall and shorter dry season, livestock are moved over shorter distances to dry season pastures in years of good rainfall. However, the inter-annual variation in rainfall in bimodal systems (44–65 per cent CV in eastern Africa; De Leeuw and Tothill 1990) is much greater than in unimodal systems (20–30 per cent for the Sahel). As a result, the eastern Africa subsystem has a much higher inter-annual variation in forage production and availability. Mobility, the strategy used to cope with this volatility, works in case of local drought but is less effective when drought is widespread.

Ranching on privately owned land dominates livestock production in the southern African subsystem. Mobile pastoralism on communally owned lands is confined to northern Namibia and parts of Botswana. Elsewhere it has been replaced by ranching systems where animal movement occurs within and between large commercial ranches in the Republic of South Africa and Namibia that provide forage and water to overcome drought.

Figure 10.2 Sahelian transhumance routes across farming systems.

Source: ILRI GIS Lab.

Pastoral herd management aims at a high proportion of cows for milk production for subsistence nutrition and sales (e.g. Box 10.2). Herd management also involves reproduction and herd growth, animal offtake and sales, grazing management and animal health care (Table 10.2). Management is flexible (FAO 2001) because pastoralists must respond to markets, security, weather, and grazing and water conditions. The pastoral farming system requires low physical inputs, but high inputs in terms of knowledge, social networks and labour. Long distance migration systems are more labour intensive than less mobile or sedentary systems (Turner et al. 2011), and labour shortage may constrict grazing, with negative effects on animal nutrition, health and herd productivity. The demand for external inputs such as animal feed increases with declining mobility.

African pastoralists are ethnically diverse, with 34 linguistic groups and 4 phyla: the Afro-Asiatic, the Nilo-Saharan, the Niger-Congo and the Khoisan (Blench 1999). The eastern African subsystem has the highest linguistic diversity (25 language groups) followed by the Sahel (11) and southern Africa subsystem (3 groups). Ethnicity influences the species kept and economic practices. The Afro-Asiatic groups are predominantly camel keepers, while the rest are primarily cattle keepers. Pastoralists respond to socioeconomic realities and opportunities, and may change their livestock specialty

Box 10.2 A pastoral household in Masaailand

A typical household consists of an elder husband, two wives, ten children and some relatives. The family lives in a Manyatta (homestead) keeping about 25 cattle under their own control. Another five to ten cattle are kept in herds of relatives and friends to maintain social ties and to minimize the risk of losing the herd from disease and drought. Also kept are sheep and goats that produce better meat and are more disease-resistant, more prolific breeders and more easily sold than cattle. The milk is partly consumed and partly sold to purchase cereals to complement the diet. The annual income from livestock sales of US\$350 in a normal year is complemented by US\$230 from remittances and tourism. During the tourist season older women live away from home near tourist centres near the wildlife reserve where they may earn US\$50–65 per week from selling beads. The increasing subdivision and privatization of land in southern Kenya complicates livelihoods as it may lead to fencing, which reduces livestock access to pasture, watering points and saltlicks, and curtails mobility during drought.

Table 10.2 Key features of pastoral management systems in sub-Saharan Africa

Management issue	Key feature
1 Herd size	Varies and tends to increase with mobility. Transhumance herds in west Africa have 50 head of cattle or more whereas sedentary herds often have fewer than 10.
2 Feed resources	Depends on natural pastures including fallows, with increasing importance of crop residues, weeds and roadsides in west Africa. Supplementary feeds are rare but increasingly given to lactating cows or fattening animals.
3 Herd management	Herd mobility, herd diversity (different species and breeds), optimized number of females and herd splitting practised to enhance herd growth and reduce risk.
4 Grazing management	Inter-annual variation in grazing itineraries because of variable availability of forage and water. Night grazing is common in west and eastern Africa.
5 Herd reproduction and breeding	Pastoralists control reproduction, particularly in cattle, through selective mating. All females reproduce, but only a few good males are kept while the rest are sold.
6 Herd growth	Reproductive females enter herds through birth, inheritance, loans, animal exchange and purchase. Mating bulls enter herds mainly through inheritance, animal exchange and purchase.
7 Animal health	Generally poor access to veterinary services due to cost and distance. Drugs and vaccines are available at markets, but quality is poor and fake products are common.
8 Women's activities	Mainly milking, processing of milk and sale of dairy products. They generally control the proceeds of sale for household nutrition.

Source: Ayantunde et al. (2011); FAO (2001).

Figure 10.3 Fulani boy in Niger herds his family animals.

Source: ILRI / Stevie Mann.

(e.g. from cattle to camel keeping); some may adopt a different economic specialization (e.g. hunting in addition to herding) while some return to their ethnic specialization, or change completely due to ethnic assimilation. The Maasai and the Samburu in Kenya, for example, have in the past adopted diverse, economic activities of herding, foraging, beekeeping, smelting and forging, and cultivation at different times (Sperling and Galaty 1990).

Women's roles in African pastoral systems are diverse, differentiated and complementary to those of men (Homewood 2008). Herding remains in the hands of young men (Figure 10.3), while older men are involved in management and negotiations over trade, marriage agreements and sanctions for infringement of customary institutions controlling resource access (Homewood 2008). Women in most cases have responsibility for house construction, movement of the camp, child-care and food, fuel and water provision. Women control milking and milk marketing (Boxes 10.2 and 10.3) with the exception of the Peulh or Fulani where men are also involved in milking. With knowledge on milk production of specific animals, women also contribute to breeding decisions. Dairy sales comprise a major, and usually the sole, source of income for many pastoral women. The sale of milk is also an important income source for women in peri-urban areas, some of whom are destitute widows (Fratkin and Smith 1995). These women can be supported to increase their income through interventions targeting improved milk marketing, especially through local cooperatives (Coppock et al. 2011).

Box 10.3 A Fulani household in the Sahel

A typical household among the pastoral Fulani in the Sahel consists of an elderly male head, two wives, six to nine children and more than two male relatives. The family has settled in the southern part of the pastoral farming system, while herders move the livestock to and from the pastures in the north during the rainy season. The household head controls resource allocation within the household. Herds on average contain about 20 cattle, of which 65–75% are female, 20–25 sheep and goats, and 2–4 donkeys. Two or three of the cows and/or heifers are received under the traditional habbanayé scheme, which lends cattle to related pastoralists to reduce risk and strengthen relationships. The women milk the cows and milk is consumed fresh or soured, or processed into cheese that is sold. Milk production is high from August to November when feed resources including crop residues are available. The household grows millet for household consumption on 2 to 5 ha of land. Household grain harvest varies markedly from 800 to 2000 kg per year. The household sells little of the grain produced and depends on the sale of livestock and livestock products for cash. Livestock are sold to buy cereal for home consumption, and grain and sugar for family members who are taking the animals on transhumance. Total annual income varies from US\$150–250 per person. Most is derived from livestock, while 20–40% may be from seasonal migration and off-farm income earned by adult males in the household.

The pastoral system faces risks, including drought, disease and violence, that cause volatile animal production and sudden animal loss. Drought affects the pastoral system in multiple ways. It interrupts herd growth, reduces birth rates and increases livestock mortality. It affects milk production because of lower production per lactating cow, and fewer lactating cows due to mortality and failure to conceive. The effect of drought lingers on after the rains return; milk production resumes with delivery of newborns following the regeneration of the range. However, without restocking, herds take many years to recover (Lesnoff et al. 2012). Thus, the impacts of drought are complex, involving the interaction between shortfalls in forage and water resources, starvation, weakened animals, disease and resilience of animals, rangelands and pastoralist coping strategies. There is ample information on the effects of drought on specific parts of the pastoral system. However, apart from the study on multiple effects of drought on pastoral systems in Maasailand (Bekure et al. 1991), detailed insights on how drought affects the pastoral farming system and the associated livelihoods across Africa are only beginning to emerge.

Pastoralists have developed strategies to enhance the drought resilience of their farming system and livelihoods, including livelihood diversification and strategies to prevent and cope with drought-related animal loss. Mobility to divert livestock to better pastures and water, the major drought-coping strategy (Zwaagstra et al. 2010), requires intensive social networking to obtain the goodwill of neighbouring communities when need arises. Other traditional risk aversion interventions include destocking and splitting a family's livestock over multiple, dispersed herds. Strategies to mitigate the effects of animal loss include changing species such as from cattle to camels. Pastoralists also depend on social

safety nets such as assistance from wealthier relatives to restock herds following drought. Together this mix of strategies aims to secure the livestock resource base that underpins pastoral livelihoods and restore the herds when drought ends. Poor households losing their herds during drought typically strive to rebuild their herds, but when failing they face the risk of falling into a 'poverty trap' (McPeak and Barrett 2001).

Chronic disease and disease outbreaks affect pastoral animal productivity, leading to animal loss and poverty. While disease has a significant impact on pastoral livestock, there is a danger of exaggerating the importance of disease control when reviewing its potential in isolation from other livestock losses such as drought, predation and theft. Markets and volatile cereal prices are additional risk factors, particularly during drought when the declining terms of trading livestock for cereals weakens the ability to purchase food. The pastoral farming system is further affected by local violence and insecurity, for example livestock theft and conflicts over grazing areas. External risk factors tend to be slow and creeping, such as conflicts over land and water resources, because of settlers and agencies implementing cropping, irrigation and nature conservation, all of which reduce pastoral access to land and water.

In terms of food and nutrition security, pastoralists traditionally rely on milk and to a lesser extent on meat. Milk is directly consumed or exchanged for grains. Sadler et al. (2009) demonstrated the value of milk for child nutritional security and health. However, across dryland systems, ensuring adequate milk year round is a challenge. In normal years, a shortage of milk emerges at the end of the dry season; a prolonged dry season can reduce or halt milk production, resulting in acute food insecurity. Small ruminants and camels are valued in this respect, as they produce longer during the dry season. During droughts, milk production declines even more and the remaining lactating animals need to be protected with supplemental feeding.

Meat is consumed less frequently than milk. In the west African Sahel, young animals, especially males, are sold in the market for meat and as draught animals. Pastoral systems make important contributions to local and national economies, but this contribution is underestimated (Behnke 2010). About 80 per cent of red meat consumed in Kenya is produced in the pastoral systems within Kenya and neighbouring Somalia and Ethiopia. In Ethiopia, livestock contributed 45 per cent of agricultural Gross Domestic Product in 2008–2009, much coming from the pastoral system.

Trends and drivers of change across the system

Population, hunger and poverty

Rural population densities in the pastoral farming system range from 0.6 persons per km² in southern Africa to more than 14 in the Sahel. The higher growth rates for urban than rural populations (Table 10.3) suggest an outmigration to cities within the pastoral farming system and an exit from rural areas, a trend which may continue.

Poverty is a key driver of change. Income poverty presents an incomplete picture however, as many pastoralists depend on livestock and land assets, which should also be considered in pastoral poverty assessments (Little et al. 2008).

A minimum of around 4.5 TLU per adult was required to support a traditional pastoral livelihood (McPeak and Barrett 2001). Today, pastoral diets include cereals, self-produced or purchased through sale of animal products. But even so, some 4.5 TLU per

Table 10.3 Population growth rate in the pastoral farming system for various groups

	Average annual increase (%)		
	2000–2005	2005–2010	2010–2015
Urban population	2.3	3.8	3.9
Rural population	2.9	2.1	2.1
Population in agriculture	2.5	1.8	1.7
Female in agriculture	3.5	2.5	2.5

Source: FAOSTAT.

adult is still required to generate sufficient income to acquire these cereals. Households with fewer animals are likely to fall into poverty traps, with insufficient cash income and gradually declining livestock assets because herd accrual does not compensate for sales and losses of livestock (Lybbert et al. 2004). The average per capita livestock holdings (TLU 0.97 in the Sahel, 0.61 in eastern Africa and 1.50 in southern Africa) are below this threshold in all subsystems. In Kenya, for example, per capita livestock assets have dropped because the human population growth rate exceeds that of livestock populations (Box 10.4). Thus, human population growth drives pastoral poverty, as many pastoralists have insufficient livestock to sustain a livelihood based on livestock only. This forces pastoralists to diversify into non-livestock income (Homewood et al. 2009), a trend common across rural sub-Saharan Africa.

The above stresses the importance of livestock as an asset. However, policies on poverty reduction in the developing world focus on income poverty. Income poverty is widespread in pastoral systems because many families have lost their livestock, but also because of long-term political neglect, marginalization, few economic opportunities and lack of access to services such as education and health (Little et al. 2008; Okwi et al. 2007). Prevalence of extreme poverty (<US\$1.25/day) in the pastoral system is below 20 per cent only in Cameroon, Djibouti and Sudan, while Uganda and Nigeria have extreme poverty rates of 79 and 76 per cent respectively.

Box 10.4 Population growth as a driver of change

The density of livestock in the Kenyan drylands has fluctuated but not changed much since the late 1970s (De Leeuw et al. 1998), but human populations have increased significantly. The numbers in the lower two maps in Figure 10.4 reveal that the average livestock wealth per capita was around the threshold required for a livestock-based livelihood in the late 1970s. Today this ratio has dropped to values below 1 TLU per capita in most districts. Human population growth increases the pressure on livelihoods as it reduces their livestock wealth. Most of the Kenyan drylands are arid, and a diversification towards agropastoralism or mixed crop livestock systems is possible only in the semi-arid zone. The map in the centre shows the distribution of rainfed, mixed crop livestock systems in the Kenyan drylands.

Livestock density

Human population density

Figure 10.4 Spatial variation in livestock stocking rate per area and per capita, and population density in the arid and semi-arid lands (ASAL) of Kenya between the late 1970s and late 1990s.

Source: Maps based on livestock density and land cover data from Department of Resource Surveys and Remote Sensing (DRSRS) and De Leeuw et al. (1998), as well as the human population census from Central Bureau of Statistics (CBS), Kenya.

Figure 10.5 Beneficiary of Takaful insurance payout in Wajir, northern Kenya.

Source: ILRI/Riccardo Gangale.

Income poverty can be transitory or chronic (structural). Transitory poverty refers to households lapsing temporarily into poverty due to shocks but retaining the ability to move out again on their own or through safety nets. Chronic poverty refers to households that are locked into poverty in the long term and are unable to escape without external assistance. Policies to address pastoral poverty should be tailored differently for households affected by transitory or chronic poverty. Safety net policies (e.g. emergency feeding programmes, disaster assistance and insurance) (Figure 10.5) are required to prevent households in transitory poverty from descending into chronic poverty, while cargo net policies (e.g. school feeding programmes, micro-finance and land reforms) are required to help chronically poor households (Barrett 2005).

Inequality in income and asset holdings, especially livestock and land, is another important aspect of poverty among pastoralists. Pastoral societies are commonly perceived as egalitarian, due to their communal land management, limited hierarchy, consultative decision making, the strong sense of social identity and the presence of social solidarity networks. This perception is reinforced by lower levels of income inequality (as measured by the Gini index) in pastoral areas relative to crop-based systems in Kenya. However, there is high inequity in the distribution of livestock, with few households owning most livestock (Homewood et al. 2009). This skewed distribution puts the wealthier livestock owners at an advantage over the poor in using the common pool resources such as the grazing rangelands. Table 10.4 shows the percentage of households in northern and southern Kenya with livestock holdings below 4.5 TLU per capita. In southern Kenya, there was a 24 per cent increase in the number of households in this category between

Table 10.4 Percentage of people and their income and assets in four household categories classified by livestock holdings (TLU per capita) for northern and southern Kenyan pastoral areas

	<i>Household category (TLU per capita)</i>				<i>Total</i>
	<1	1–1.99	2–4.5	>4.5	
	<i>Northern Kenya</i>				
Human population (%) (2000–2002)	32	21	26	21	100
Livestock (TLU) / capita (2000–2002)	0.34	1.43	3.17	10.18	
Income / capita day (\$) (2000–2002)	0.20	0.35	0.39	1.05	
Income livestock (%) (2000–2002)	37	38	66	77	
	<i>Southern Kenya</i>				
Human Population (%) (2009)	23	23	34	20	100
Human Population (%) (2008)	7	9	30	54	100
Livestock TLU / capita (2009)	0.35	1.48	3.14	12.74	
Livestock TLU / capita (2008)	0.06	1.44	3.25	13.45	

Source: Northern Kenya data (Little et al. 2008) and southern Kenya data (Osano et al. 2013).

2008 and 2009 due to drought. The table also shows a strong association between asset and income poverty – those with fewer animals also have less income.

Further, privatization and subdivision of pastoral land tend to increase gender disparity and inequity and widen the gap between the poor and the wealthy (Lesorogol 2003). This stratification among pastoralists into a relatively wealthy minority and a poor majority has implications for the economic choices and the livelihood diversification strategies adopted: (1) poverty strategies driven by necessity, often involving poor and marginalized households; (2) risk-management strategies in response to unpredictable and changing ecologies and economies, often involving moderately well-off households; and (3) strategies aimed at investment and accumulation of wealth, principally involving the richest households (Homewood 2008).

Natural resource management and climate change

There has been much debate about the resource-base-degrading effect of mobile livestock. An earlier theory, that mobile pastoral animal production results in overgrazing and resource degradation, has been challenged by an alternative theory that rangelands are non-equilibrium systems, where stocking density does not reach levels high enough to negatively affect rangeland production (Behnke et al. 1993). Following this paradigm shift it has been taken for granted that the non-equilibrium theory holds for pastoral lands. Modelling studies suggest that non-equilibrium conditions hold above a coefficient of variation (c.v.) of annual rainfall of 33 per cent. However, the larger part of the pastoral farming system, including most of the Sahel and the east African drylands has a c.v. of annual rainfall lower than 33 per cent (Figure 10.6), implying that livestock may reach equilibrium with rangeland resources and thus may degrade these resources. This result questions whether the non-equilibrium model holds for most pastoral lands and highlights a need for system-wide evidence on the state of rangeland resources and the impacts of livestock on them. Satellite-based remote sensing may assist in mapping the condition of rangelands over large areas; it does not, however, give information on the processes

Figure 10.6 Distribution of lands with coefficient of variation of annual rainfall higher and lower than 33%.

causing vegetation and land degradation. Long-term monitoring and experimental plots are required to understand vegetation and rangeland change processes.

Another way to approach natural resource management in rangelands is to consider the amount of biomass (forage) produced in relation to the rainwater used for this. Rain Use Efficiency (RUE) is the biomass produced per unit of rain, which varies in rangelands in Africa and elsewhere from 1 to 8 kg.ha⁻¹.mm⁻¹. Recent meta-analysis by Ruppert et al. (2012) confirmed the earlier suggestion (de Leeuw 1991) that increased livestock stocking densities are associated with reduced RUE. Given that C4 grasses have a potential RUE of 50 kg.ha⁻¹.mm⁻¹, the GWUE (green water use efficiency, the percentage of rainwater used for transpiration) of African rangelands varies between 2 and 16 per cent. This contrasts with GWUEs of up to 55 per cent achieved under similar conditions in the United States with better soil evaporation control (Slegers and Stroosnijder 2008). One way to enhance GWUE in rangelands could be managing grazing animals to retain sufficient vegetation cover protecting the soil. However, better soil and water management alone does not necessarily lead to increased livestock production because forage protein content tends to be higher where rain limits production than in more humid areas where low soil nitrogen results in low plant protein concentrations. The Sahel with <300 mm rainfall has protein concentrations of 12 to 18 per cent; in wetter areas where nitrogen is limiting protein concentrations fall below the 7 per cent required to maintain livestock body condition (Breman and De Wit 1983). Arid lands, with their low biomass, allow high livestock productivity and herd growth because of this; they contrast with more humid areas that, although having

ample biomass, lack the forage quality to support productive livestock. GWUE enhancement strategies aiming at greater forage biomass will thus not necessarily increase livestock production; concurrent strategies are required to enhance soil fertility and forage quality.

Availability of and access to natural resources also affect the sustainability of the pastoral farming system. Excision of key pastoral resource areas or blocking access to them places great pressure on livestock mobility and upsets the functioning of the pastoral system (Niamir-Fuller 1999). Land use changes driven by demographic pressure, market expansion and increased private and public investment in pastoral areas, limits access to land and water, particularly when land is diverted from pastoral use into crop-based agriculture (Box 10.5). Abstraction of riverine water in highland areas, leading to reduced flows for downstream water users, also marginalizes pastoral resource users. Loss of availability and access to resources is also driven by policies favouring crop-based land uses and upstream water users. Appropriate policies are required to ensure that the traditional beneficiaries of these resources remain able to determine their future use.

The potential impacts of climate change vary regionally and may affect the productivity of pastoral ecosystems, increase food insecurity and cause a decline in GDP from livestock (Eriksen et al. 2012). The specific impacts of climate change on natural resources include changes in availability and quality of forage resources, access to water, species and breeds of livestock that can be kept, livestock mobility and conflict over natural resources. Climate change will likely affect forage availability and quality through changes in herbage growth and quality, floristic composition and importance of crop residues as animal feed. Forage resources will be further modified by climate-associated changes in soil fertility, land use and grazing management. Finally, an increase in extreme rainfall may affect forage yield more than any changes in the mean annual precipitation. The likely impacts of increased temperature on forage quality will be lignification of plant tissues with an associated decline in digestibility, while increases in CO₂ concentration will lead to more C3 species and dicots.

Box 10.5 Land use as a driver of change in the Sahel

The transhumant system in the western Sahel is exposed to a number of drivers of change (Ayantunde et al. 2011). Livestock trade has increased as a result of rising demand for animal protein in the growing coastal economies. At the same time land use change towards agropastoralism in the southern Sahel competes with pastoralism for land and water. In response to this, the wet season grazing has shifted northwards to divert livestock from croplands in the south. Concurrently there also has been a deeper penetration to the south by transhumant herds, attributed to the droughts of the 1970s and 1980s and the expansion of cropping into grazing areas in the Sahel. During the droughts, some pastoralists settled to grow crops and raise livestock as far south as northern Côte d'Ivoire and Benin. These settled pastoralists often serve as contacts for the transhumant herders, playing a key role in negotiating access to grazing resources and in resolving conflicts. These developments have led to an increased length of transhumance routes. The costs of this are further aggravated by a multiplicity of taxes levied by local government. These have increased with decentralization policies and laws which, while aiming at strengthening local government, have resulted in collection of additional revenue through local taxation (Ayantunde et al. 2010).

Energy

Pastoralists use renewable bioenergy in various ways. Bush fire suppresses shrubs and is used as a management tool to maintain rangelands in a grassland state. Fuelwood is used for cooking, heating, lighting and deterring predators. Pastoralists' fuel requirements have increased following diversification to mixed diets composed of animal produce and cereals, which, unlike milk, need to be cooked to release full caloric value. Pastoralists also complement their income through production and sales of fuelwood and charcoal derived from rangelands. Together these various uses result in significant biomass extraction, but thus far there has been little study on the energy footprint of pastoral livelihoods.

Science and technology

Improvements in livestock productivity have been supported through breeding and the control and management of livestock diseases such as rinderpest, east coast fever (ECF) and trypanosomiasis. Key constraints in addressing animal diseases are the lack of low-cost, easy-to-use diagnostics, vaccines and control strategies for disease organisms and vectors. Recent advances in biotechnology could potentially lead to improvements in the diagnosis of livestock diseases; and genomics can support the development of a new generation of livestock vaccines, leading to successful livestock disease control and positive impacts on poverty reduction among livestock keepers (Perry and Grace 2009).

Advances in information and communication technologies (ICT) also provide opportunities for increased production, management and marketing of livestock in the pastoral farming system. ICT gives improved access to markets and price information that allows pastoralists to identify the points of sale with the most competitive prices for livestock and livestock products, and reduces financial transaction costs by using mobile money transfer services. Other potential benefits of technology include radio frequency identification (RFID) chips widely used in the southern Africa subsystem for cattle traceability. This enables the monitoring of animals, reduces risks from theft and controls bovine diseases such as foot and mouth disease.

GIS-based spatial technologies can also facilitate improved land management through mapping and planning, and by providing information on pasture and forage availability in response to variable weather. This information is essential for pastoralists to move strategically with their herds, to mitigate potential conflicts and to implement weather-based livestock insurance for herders, such as the Index Based Livestock Insurance (IBLI) being implemented in northern Kenya and southern Ethiopia to safeguard pastoralists against drought-related livestock losses. IBLI provides compensation based on area-average livestock mortality, predicted using the Normalized Difference Vegetation Index indicator derived from remote sensing satellites (Chantararat et al. 2012).

Lastly, numerous rainwater harvesting and soil-water retention technologies for crop production have been developed that have the potential to improve productivity, particularly in semi-arid areas. These can contribute to pastoral system diversification towards integration of crop and livestock production in agropastoral systems or support settlers used to crop-based agriculture who have moved into the pastoral system.

Markets and trade

Trade is an integral part of the pastoral system, but new challenges and opportunities are emerging. These include: (1) the increase in local and global demand for milk

and meat products, particularly in growing urban areas, which is driving domestic and export market growth; (2) the growing commercialization and penetration of domestic and foreign capital into the pastoral system, including private and government investment in infrastructure and technology; (3) climate change, including frequent droughts where pastoralists use markets for destocking, although often terms of trade have by then turned against them and they may hold onto animals; and (4) the increased need for diversification among different types of pastoral households (see section on population, hunger and poverty).

Like in other farming systems, richer pastoralists generally benefit more from market participation than do poorer ones (Aklilu and Catley 2010). Reasons for this include the minimum herd size needed for viable market-oriented production; cash available to buy animals and herds; social capital and information needed to negotiate good prices; access to credit; and transport infrastructure. Consequently, poor and wealthy households have different market strategies. The poor tend to trade more small stock because these require less cash to buy and sell. Wealthier herders have the capital to add value through fattening animals close to terminal markets, and they invest in larger and higher value cattle. The livestock supply chains in east Africa are becoming more stratified as they specialize to serve different market segments, and it is generally the wealthy that benefit from the expanding export markets. Pastoral production is still predominantly herd reproduction and milk, and thus increased commercial activity in meat sales poses the question how a broader group of pastoralists can engage in sales and in value-added activities. Otherwise the growth in meat demand is likely to benefit only wealthier pastoralists.

Pastoralists have long relied on local and cross-border trade and markets to purchase food and other commodities, especially in dry seasons when livestock productivity is low. With growing demand for livestock products, the income earned from livestock sales is increasingly important for household food security. There are key differences in livestock trade across regions and in national and regional policies supporting domestic and international (export) trade (e.g. Hesse and Cavanna 2010). In the southern African subsystem, especially in Namibia, Botswana and Zimbabwe (until recently), export-oriented production for Europe has been enabled and encouraged. In the west African Sahel, the north-south regional trade networks and proximity of large urban centres to pastoral and agropastoral areas have allowed domestic and regional livestock markets to flourish. In eastern Africa, there has been little state support for pastoral livestock markets, even though livestock contributes a significant percentage to national economies (Hesse and Cavanna 2010). The exports from east Africa to the Middle East remain important, and donors continue to invest in export schemes (Aklilu and Catley 2010). A key trade challenge remains the ability of African pastoral livestock producers to be competitive in international export markets given the low availability of veterinary services and limited capacity for adherence to sanitary and veterinary standards. With growing milk and meat demand, and customers expecting continuous supply, pastoralists need to become a more stable supplier of livestock commodities, notwithstanding the boom and bust cycle that characterizes pastoral livestock production.

Policies and institutions

The pastoral farming system is affected by many global, regional and national policies. The critical among these deal with governance and political participation (including security), economic development (including for agriculture, livestock and markets), natural

resources (including land, biodiversity and water) and development cooperation (including aid and humanitarian assistance). In previous decades, inappropriate policies and development interventions, which favoured crop-based agriculture and sedentary livestock production futures, have challenged pastoralism and associated livelihoods. Historically, this inappropriateness has stemmed from a lack of pastoralists' participation and influence in decision making.

In recent years, policies have demonstrated a new-found support for pastoralism in general, and the pastoral poor particularly. Policy attention is also increasingly targeting conservation of the rangeland ecosystem, the facilitation of transboundary livestock movements and inclusive local policy processes. Policy and legal instruments are now formalizing pastoral people's rights. In 2010, the African Union established a Continental Pastoral Policy Framework, which aims to: secure and protect the lives, livelihoods and rights of pastoral peoples and ensure continent-wide commitment to political, social and economic development of pastoral communities and pastoral areas; and reinforce the contribution of pastoral livestock to national, regional and continent-wide economies. In eastern Africa, the Inter-Governmental Authority on Development (IGAD) and Food and Agriculture Organization (FAO) established a Livestock Policy Initiative (LPI) in 2009 to address the policy and institutional changes needed for the poor to benefit from enhanced livestock production. Through the LPI, 'policy hubs' are being put in place in member states to coordinate national-level processes. In the west African Sahel, the recent N'Djamena Ministerial Declaration of May 2013 mobilized participants from 17 countries to support strong governance, resilience, and social and economic viability of pastoralism in Saharan-Sahelian areas.

With respect to natural resources, the impact of land tenure policies on pastoral land and land use has been particularly profound. Traditional, indigenous land tenure has moved to modern, formal tenure systems in many areas as states have formulated and enacted land laws, policies and programmes to formalize property rights for land in pastoral drylands (Lengoiboni et al. 2010). This transition is accelerated by policies aiming to promote privatization of land, transforming pastoral resources from common property in which multiple users negotiate and compete for rights, to private individual property where land use regulation, access and exploitation is by an individual or corporate entity (Homewood 2004). These privatization policies are based on the premise that formalized tenure will lead to increased investment in land, a premise that remains debatable.

In eastern Africa, land is state-owned in Ethiopia and Tanzania, while Kenya has largely privatized pastoral lands in the south and communal tenure on trust land in the north and east. Uganda and Tanzania have both recognized customary and group rights in the land statutes entailed in the Tanzania Village Land Act (1999) and Uganda Land Act (1998), but their implementation remains ineffective among pastoral communities.

In the more intensive southern African subsystem, land privatization is more advanced than in the west African Sahel where pastoralists continue to migrate across vast swathes of communal, open access land that often spans multiple countries. The privatization of pastoral lands in southern Kenya developed in two steps, from formalizing collective ownership to subdivision of this collective property to individual tenure (Mwangi and Ostrom 2009). The outcome of privatization has not all been positive. The process has led to inequitable land distribution among households, and the exclusion of women and youth from land ownership as well as increased poverty because of indiscriminate and distress land sales. Furthermore, privatization has impacted pastoralism negatively while restricting livestock mobility with negative consequences for pastoralists during periods of drought (Nkedianye et al. 2011).

The fragmentation of rangelands also inhibits movement of wildlife, especially large mammalian herbivores, leading to increased human-wildlife conflicts around protected areas in the pastoral subsystems in eastern and southern Africa. Consequently, pastoralists are responding by developing new land management arrangements involving formalized rights to land through land titling and the reconsolidation of subdivided land to give access to grazing and water resources (Mwangi and Ostrom 2009). In wildlife-rich areas such as in Kenya and Namibia, this process also involves the establishment of conservancies, which seek to balance livestock and wildlife land use planning and allow pastoral communities to diversify and benefit from wildlife tourism (Box 10.6).

Box 10.6 Community conservancies as innovations for land and wildlife management in Kenya and Namibia

Community conservancies are widespread in the pastoral rangelands in Kenya and Namibia. Conservancies aim to promote better governance and benefit-sharing from wildlife and tourism. In Namibia, local communities have embraced conservancies as a means to manage wildlife and tourism activities on their land. By the end of 2010, there were 59 registered communal conservancies in Namibia, managing more than 132,697 km², accounting for 16.1 and 42 per cent of the total land area and communal lands in Namibia respectively. The conservancy approach is becoming effective as a conservation strategy, as demonstrated by the increase in wildlife populations and decrease in human-wildlife conflicts in communal areas. Conservancies also provide socioeconomic benefits such as income for local communities, employment opportunities and development of new skills and expertise, but their impacts on livestock production are less documented. The benefit-sharing occurs in six main categories: conservancy operational costs; payment of salaries for staff; direct payments to villages or individual conservancy members; contribution to capital development (e.g. construction of water infrastructure for people and livestock); investments in social programmes, including health clinics, education, support for HIV/Aids afflicted families and soup kitchens for pensioners; supply of game meats to families and local schools; and pooling of cash income for investments in business and income-generating activities.

In Kenya, in 2010, there were a total of 41 community wildlife conservancies in the pastoral arid and semi-arid lands (ASAL), covering close to a million hectares (Osano 2013). A critical aspect of conservancies in Kenya is the land tenure system; over 65 per cent of all the conservancies are located in group-owned communal lands with the remaining 35 per cent found in privatized lands. Some 24 per cent of the conservancies provide direct cash payments to pastoral households in return for managing land for wildlife conservation and tourism, based on a payment for ecosystem services model. These conservancies generate money from both public and private sector sources in the tourism industry. In southern Kenya, conservancies have contributed to the reconsolidation of subdivided and fragmented lands, bringing these lands under common management. In northern Kenya, conservancies are promoted as an incentive to prevent the privatization and subdivision of currently communally held, group-owned pastoral lands. In addition, conservancies have provided a 'safety net' to pastoral communities during drought periods, and these benefits are expected to increase and become more important with climate change.

In terms of development assistance, the Official Development Assistance (ODA) investments in pastoral communities have been sparse at best, relative to assistance provided to development in general and crop-based agriculture specifically. The ODA for agriculture in sub-Saharan Africa decreased by 35 per cent between 1980 and 2005, notwithstanding a 250 per cent increase in overall ODA commitments over that period. It is unclear how much of the ODA is invested in pastoral livestock production, if any. Much of the resource invested so far has been directed to, and continues to be absorbed by, emergency relief and humanitarian assistance rather than development.

Human capital/knowledge sharing/gender

Generally, mobile pastoralists have been neglected by governments and excluded from social services. This has profound implications in terms of types of education and equity among the children educated. Beyond sheer remoteness, key constraints tend to be demand for children's labour (FAO 2013), insufficient and inappropriate training infrastructure and curricula, and difficulty in retaining teachers. Some African countries are providing fixed and mobile community schools, which involve pastoral people in the education design. Gender inequity, with much lower rates of enrolment for girls than boys, is increasingly being addressed. The provision of formal education also transforms local patterns of knowledge generation, production and dissemination, leading to a fusion of indigenous and scientific knowledge. Pastoralists' indigenous knowledge remains highly relevant in rangeland and livestock management, traditional veterinary services and drought forecasting, which can contribute to adaptation to climate change as exemplified by the pastoralists in the Sahel.

Other services such as extension and advisory services have been far from appropriate both in content and approach. Butcher (1994) highlighted that beyond the inevitable difficulties associated with low populations in large land areas, traditionally extension through public sector advisory services does little to support long-term livestock and pastoral development. Traditional extension follows more of an economic development approach that is technologically biased and targeted at sedentary, male livestock keepers. What is needed is a social approach addressing a full complement of integrated services including health, water, range management and veterinary care. While improvements have been made in participatory approaches such as community animal health care, the formation of water commissions, and livestock insurance schemes, there is room for improvement in participatory planning approaches and institutional development within these systems (Butcher 1994; REGLAP 2012).

Pastoralists are in a continuous cycle of innovation and adaptation. For example, the use of mobile telephones, now with solar rechargers, has dramatically changed traditional pastoral practices due to faster and reliable access through mobile phone and internet to information, including on rangeland quality, water points, weather patterns, disease outbreaks, markets and prices. This also allows pastoralists to send and receive money virtually, circumvent insecurity, be involved in distance learning and participate in various processes remotely.

System and subsystem performance

There are ample case studies, but no synthesis exists on the system performance of the pastoral farming system. Table 10.5 summarizes the performance of the three pastoral subsystems in terms of productivity, sustainability and human development outcomes.

Table 10.5 Performance of the three pastoral farming subsystems in terms of productivity, sustainability and human development outcomes, based on available data and expert assessment

<i>Performance indicator</i>	<i>Sahel</i>	<i>Eastern Africa</i>	<i>Southern Africa</i>
<i>Productivity</i>			
• Rangeland extent ¹	Declining	Declining	Stable
• Rangeland productivity ²	Stable (on average)	Stable (on average)	Stable
• Use of crop residues ³	Used	Not used	Low, declining
• Milk production ⁴	Low, stable	Low, declining	Low, declining
• Livestock offtake ⁵	Low, increasing	Low, increasing	Low
<i>Sustainability</i>			
• Biophysical ⁶	Mixed	Mixed	Mixed
• Economic ⁶	Mixed	Mixed	Mixed
• Social ⁶	Mixed	Mixed	Mixed
<i>Human development</i>			
• Food security ⁷	Insecure	Insecure	Secure
• Health care services ⁹	Poor	Poor	Medium
• Education ¹⁰	Poor	Poor	Medium
• Poverty ⁸	High	High	High

Notes: 1 – Expert assessment of land use change; 2 – Vrieling et al. (2013), analysis of change in length of growing period from NOAA AVHRR NDVI data 1983–2011; 3 – expert assessment; 4 – expert assessment and Bouwman et al. (2005) for eastern Africa; 5 – Expert assessment and Bouwman et al. (2005) and Norton-Griffiths and Said (2010) for eastern Africa; 6 – effects are mixed and further described in the text; 7 – Headey (2011); Moritz et al. 2009; Nguyen 1998; 8 – this chapter, Table 10.1; 9 – expert assessment; 10 – expert assessment.

Productivity

The overall productivity of the system is affected by the extent and productivity of rangelands. The extent of rangelands is declining in the Sahel and eastern Africa, due to land use change towards crop agriculture. Although fluctuating from year to year, rangeland productivity appears to have been stable since the late 1980s, as seen from long-term satellite imagery. Figure 10.7 shows that length of growing period has been stable for part of the pastoral farming system, while it varied in other parts (Vrieling et al. 2013). Conditions improved in the southern Sahel, while for some areas within the Sahel and eastern Africa (for Kenya only for the short rains starting around November), a reduction in length of growing period was observed. This could indicate that locally, rangeland productivity is declining. Another productivity indicator is the usage of crop residues, which are widely used in the Sahel and northern Africa, while there is potential for integration between crops and livestock in the other two subsystems.

Livestock productivity includes the production of milk and offtake of live animals (for meat), which is based on the growth of herds. Pastoral cattle milk production ranges from 0.5 to 2 litres per lactating cow per day (Bremner and de Wit 1983). Mean annual increases in cattle herd live weight of 20 to 25 per cent are reported from the Sahel and Masailand (Bekure et al. 1991; Bremner and de Wit 1983). Table 10.6 forecasts an increase in offtake rate and reduction in milk production in the eastern Africa subsystem and significant increases in beef offtake until 2030. Lack of data limits the ability to assess changes in livestock productivity in the Sahelian and southern African subsystems.

Figure 10.7 Change in length of growing season (LGS) across sub-Saharan Africa. Green = significant (Spearman rank correlation, $p < 0.10$) lengthening, purple = significant shortening of LGS. The inset on the right shows the same for areas in east Africa with a double season where the start of the second season is around October. Red lines demarcate boundaries of the pastoral farming system. Data is based on retrievals (1981–2011) from the Normalized Difference Vegetation Index (NDVI) dataset from the NOAA's Advanced Very High Resolution Radiometer sensor using a local threshold method.

Source: Vrieling et al. (2013).

Table 10.6 Productivity of cattle, goats and sheep (shoats) and dairy in the pastoral system in eastern Africa.* Carcass weight and milk production in kg per year per animal, offtake rates in fraction per year of total animal population

Year	<i>Carcass weight</i>		<i>Offtake rates</i>		<i>Milk production</i>
	<i>Beef cattle</i>	<i>Shoats</i>	<i>Beef cattle</i>	<i>Shoats</i>	<i>Dairy cattle</i>
1970	127	13	0.09	0.26	462
1995	76	12	0.10	0.25	328
2030	70	18	0.16	0.34	329

* Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Mauritius, Mayotte, Reunion, Rwanda, Seychelles, Somalia, Sudan and Uganda.

Source: Bouwman et al. (2005).

Sustainability

Earlier we reviewed the productivity of the pastoral farming system in response to some external drivers of change. This section reviews the capacity of the farming system to provide the biophysical, social and economic services and benefits in the long term, considering both internal and external drivers of change.

Biophysical sustainability

The conversion of rangeland to crop farming is affecting the provisioning of livestock commodities from the pastoral system. Although small in area, this effect is important because agriculture expands onto the more productive grazing lands. External drivers include climate change, which may lead to greater variability in rainfall, and increased incidence of drought, which challenges the resilience and sustainability of pastoral systems. Internal drivers of change include human population growth, the impact of grazing animals on soils and vegetation, and the impacts of range management and bioenergy extraction on forage availability. The rapid increase in human population together with deepening poverty in the pastoral system is likely to negatively affect productivity in three ways. First, land use change that favours crop production reduces the extent of pasture for livestock. Second, poverty and hunger reduce the availability of labour and lead to distress sales of livestock, reducing per capita livestock holdings. Third, our analysis (Figure 10.6) indicates that non-equilibrium theory does not apply to most areas of the pastoral farming system, which means that rangeland use by livestock is not always sustainable. The effects of bioenergy extraction are mixed; where it results in removal of trees and shrubs and higher grass production it will have positive effects on cattle productivity and negative impacts on browsers; additional negative effects can include carbon emissions and land degradation.

Economic sustainability

Mobile pastoral systems have higher economic returns per unit of land than ranching systems. In semi-arid areas, however, higher returns per unit of land used for cropland drives the conversion of rangeland to cropland (Norton-Griffiths and Said 2010). Despite this, large parts of the pastoral system remain under pastoralism because of cultural reasons, including the preference for livestock keeping, the desire not to depend on external

inputs and labour, and the weather-related risk of crop failure. There are claims that climate change will alter the recurrence and intensity of drought, and that with progressive climate change, lands converted to crops may well revert to mobile livestock keeping as a more drought resilient option. However, the impact of climate change remains uncertain because of a lack of consensus on future rainfall trends.

The ongoing decline in livestock resources per capita is a major factor undermining the economic sustainability of the pastoral system, because it leads to increasing numbers of families with too few animals to sustain an economically viable, livestock-based livelihood.

Options for economic growth exist in expanded market orientation for commodities from the pastoral farming system. The development of trade, markets and associated investments in infrastructure such as roads and transport facilities, grading systems and traceability has a positive effect as it brings demand closer to the producers. Science, technology and improved human capital have a positive impact on livestock productivity but are generally more available to the wealthier pastoralists that have better access to capital, markets and improved disease-control drugs and techniques. There is also potential for growth in markets for biofuels and ecosystem services such as carbon, biodiversity and wildlife conservation (Figure 10.8). The conservancies in Namibia and Kenya where

Figure 10.8 Game farming business operation in Eastern Cape, South Africa called Ezulu Game Reserve, providing trophy hunting of extra-limital species such as sable antelope (seen here on the photograph), waterbuck, giraffe, red lechwe and impala. In the Republic of South Africa and Namibia, former livestock farms (cattle, sheep and goats) have been purchased by foreign investors and developed with luxury lodges for the trophy hunting business.

Source: Tony Palmer.

pastoralists benefit from livestock and income from wildlife-based tourism are an example (Box 10.6). To date, however, the involvement and benefits to pastoralists from carbon markets have been limited, but this could be improved through voluntary mechanisms such as the Verified Carbon Standard that seeks to facilitate social benefits from carbon markets. Finally, education has an important positive effect on economic sustainability.

Social sustainability

Pastoralists' livelihoods revolve around livestock and natural resources, especially land and pasture. In addition to providing nutritional benefits, livestock are also valued for social identity, as a means of establishing and maintaining social ties (e.g. through marriages), and for insurance purposes. Land, which is traditionally owned communally, is also critical as a substrate for natural resources including forage, pasture and water. Pastoralists create social bonds and norms in the form of social relationships and networks, which include bonding ties among families and friends within a community, and bridging ties to outsiders for political support and information. The social sustainability of the pastoral system depends on pastoralists' responses to social, economic and environmental changes (Galvin 2009). These affect the four central features of social capital: relations of trust; reciprocity and exchanges; common rules, norms, and sanctions; and connectedness in networks and groups (Pretty and Ward 2001). Pastoralist social institutions and networks are important for migration and transhumance, but these networks and larger social capital are breaking down due to a combination of factors, principally increased socioeconomic stratification along wealth, assets, land privatization, insecurity, conflicts leading to famine, and political and policy changes. Increasing socioeconomic stratification among pastoral communities compromises relations of trust and diminishes the effectiveness of traditional institutions of reciprocity and exchange. Wealthier families increasingly derive their norms and values from the modern state rather than from traditional society, thus undermining the impact of customary rules. In addition, poverty occasioned by low per capita livestock holding means that poor pastoralists are unable to help each other.

Rangeland privatization has also expanded the gap between wealthy and poor pastoralists. The wealthy can now exclude the poor from their privatized land and sometimes restrict them from accessing water resources, while still making use of common pastures, saltlicks and communal water pools, leading to mistrust and conflicts (Lesorogol 2003). The subdivision of privatized land also diminishes collaborative management of resources due to an increase in individually controlled pastures and water, loss of cultural traditions as pastoralists sedentarize, and a reduced number of people living together in common homesteads. Since the late 1990s, there has been a growing trend of absentee ownership of livestock herds (particularly cattle) in west African Sahel (Toure et al. 2012). These absentee owners are often salaried workers and relatively well-to-do business people based in urban areas who invest in livestock and contract them to herders (pastoralists) to manage. Some of these absentee owners are of pastoral ethnic origin but are no longer engaged in pastoral farming due to education and salaried jobs. The caretaking agreements with the herders are often complex depending on the relationship with the absentee owners. One common trend in managing these herds is that the absentee owners restrict the herders from taking their herds far away to ensure regular monitoring and to prevent theft. The immediate implication of a growing number of absentee owners and the associated short distance grazing itineraries is exacerbation of competition for grazing resources and conflict.

Political insecurity, including violent conflicts in the form of cattle raids, and competition for pasture especially in the dry season, are leading to changes in land use and

movement patterns, decreasing the effectiveness of traditional social networks (Pike 2004). The social sustainability of the pastoral farming system will depend on the development of social resilience where pastoralists learn from past experiences and actively integrate new knowledge to control their access to resources in new ways. This may include strengthening of bonding and bridging ties such as new forms of post-privatization, collective range-land management in southern Kenya and the development of pastoralists' associations that promote conflict resolution, peace building and resource management.

Human development outcomes

The southern Africa subsystem performs better than the Sahelian and eastern African subsystems for three out of the four human development outcomes: food security, access to health services and education (Table 10.5).

Food security in the pastoral farming system is volatile given the high inter-annual variation in rainfall, which affects productivity of livestock, milk and meat. In years without drought, the nutritional status of pastoralists during the dry season is better than that of sedentary, crop-producing populations in rural Africa. During drought, however, both eastern Africa and the Sahel are prone to famine and heavy reliance on relief food supplies (Headey 2011). Given the erratic availability of rainfall, attempts to achieve greater food security require either greater stability of forage and water supply, for example forage reserves (grass banks), or non-livestock-based interventions such as alternative sources of income and social safety nets. In the long term, interventions to promote food security can be achieved through policies and institutions that promote resilience, such as timely livestock-saving interventions during droughts, maintenance of mobility to support livestock production, livestock insurance and commodity markets (Devereux 2009; Headey 2011).

In general, healthcare service delivery is poor in the pastoral farming system because of remote conditions, low population density, poor infrastructure and pastoral mobility, which increases the costs of delivery and constrains health delivery (Sheik-Mohamed and Velema 1999). Mobility and drought are critical determinants of health status of pastoralists. Although water and pasture are common reasons for migration, pastoralists also move to avoid certain human and livestock diseases. During their movements, nomads can be active transmitters of diseases to their host communities. Conversely, they can also be passive acquirers of diseases when they are exposed to health hazards. Droughts lead to high concentration of pastoralists in relief camps, where they suffer from very high mortality rates (Sheik-Mohamed and Velema 1999).

Healthcare provision is better in southern Africa than in the Sahel and eastern Africa subsystems. Improvements in healthcare service delivery to pastoralists should include both direct and indirect interventions (Prothero 1994). Direct interventions include immunization and vaccination especially for measles; malaria vector control combined with drug protection for high risks groups such as pregnant women and children under five; provision of primary health care (PHC) through integrated fixed and mobile health units that are established according to local patterns of seasonal movements; and the recruitment and training of nomadic, community health workers to work among pastoralists (Sheik-Mohamed and Velema 1999). Indirect interventions include the provision of food that is adequate in quantity and quality to reduce susceptibility to diseases related to malnutrition, and supply of clean water and sanitation (Prothero 1994). In addition, there is need for collaboration between public health and veterinary services to meet essential health interventions for people and livestock in remote rural areas. This can, for example, be

achieved through joint vaccination campaigns for livestock and people, which have been successful and highly appreciated by nomadic pastoralists in places such as Chad.

The provision of education in the pastoral farming system is also a challenge, hence the low levels of access to basic and secondary education among pastoral communities. An assessment of the education of nomadic peoples in eastern Africa found that gross enrolment ratios (GER) for primary education in pastoral areas was less than half of the national ratio (Carr-Hill 2005). In Kenya, studies show that pastoral areas account for 18 per cent of Kenya's primary school-age children, but have 46 per cent of the absenteeism, and that less than 10 per cent of children that enrol can reach the last grade of primary school (Watkins and Alemayehu 2012). In addition to increased investments in education facilities, especially around trading centres, provision of mobile and distance-learning opportunities for pastoralists should be encouraged. Improved access to quality and appropriate education is considered the most important pathway for improving human development and can enable pastoralists to successfully diversify into non-farm activities through acquisition of new skills.

Income poverty is another key constraint to food security and human development in the pastoral system in Africa. Families with low income cannot afford to purchase food and do not have enough milk-producing animals, hence they suffer from malnutrition. Low incomes also mean not being able to afford curative health services, medical treatments and education for children. Poverty reduction interventions have great potential for improving human development outcomes in the pastoral farming system, but to date, pastoralists' inclusion in poverty reduction programmes has been inadequate and insufficient.

Strategic priorities for the system

Dixon et al. (2001) assessed the potential of five different pathways to allow 50 per cent of the poor in this farming system to escape poverty by 2015. That assessment ranked exit from agriculture higher than the other options in agriculture (Table 10.7). The assessment in 2015, which was done by the authors of this chapter, reaffirms exit from agriculture as a prime poverty escape pathway. This option needs serious consideration by policy makers and pro-pastoral donors and NGOs because of the dwindling per capita livestock wealth and resulting, ongoing exit from livestock keeping.

Exiting pastoralism requires a package of policy interventions. First, some pastoralists, especially the educated ones, can be absorbed into the formal labour market in local industries (e.g. mining and tourism) and urban areas enabling them to escape poverty.

Table 10.7 Relative importance of household livelihood improvement strategies

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total ag pop	–	40	60	100
Intensification	4	1	4	3
Diversification	1.5	1	3	2
Increased farm size	1.5	0	0	0
Off-farm income	2	3	1	2
Exit from agriculture	1	5	2	4

Sources: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

Second, some pastoralists may migrate into other systems, as occurred during the droughts in the Sahel when pastoralists migrated and settled in the neighbouring agropastoral system. Lastly, the most poor – stockless, landless, uneducated and unskilled – may exit pastoralism and spiral further into poverty due to a lack of skills and capital to adopt alternative livelihoods. For this group, exit from pastoralism is usually involuntary and extremely painful. It is a forced choice when all the livestock is lost without the prospect of returning to livestock keeping. The extreme reluctance to leave animal-based agriculture is understandable, because a life without livestock typically results in further spiralling into poverty and food aid dependency. Policy often does not recognize this gloomy perspective, neither does it provide the social and educational support needed to establish the personal ambitions, self-confidence and competencies required for a future outside pastoralism – particularly if the knowledge and skills required are fundamentally different from pastoralism. Dedicated policies are required to develop alternatives for pastoral dropouts and provide education support. This is most urgent in eastern Africa and the Sahel (Table 10.8). It is less urgent in the southern African subsystem where population densities are lower and education is already more attainable for the largely sedentary population.

Intensification, diversification of the farming system and off-farm income are other poverty escape pathways. Increased farm or herd size was considered impracticable by our peers because this would require reducing the farm or herd size of other livestock keepers, an agenda that is not manageable in the resource-constrained drylands of Africa. In extensive livestock production systems, intensification generally refers to the process of replacing traditional subsistence production with systems that range from very small-scale to medium-scale commercial production, which implies breed improvements and a certain degree of confinement (hence less mobility), access to more nutritious feeds, potable water and vaccines, and specialized skills in animal health, care and nutrition. Table 10.8 summarizes the relative importance of several poverty escape pathways in the three subsystems.

Table 10.8 Relative importance of five poverty escape pathways in the pastoral system in the Sahel, eastern Africa and southern Africa based on the expertise of chapter authors

<i>Poverty escape pathway</i>	<i>Sahel</i>	<i>Eastern Africa</i>	<i>Southern Africa</i>
<i>Intensification</i>	+++	+++	+++
• Settlement	+++	+++	++ ^{5,6}
• Tenure security	++ ^{1,2,5}	+++	
• Market orientation		++ ^{1,2,3,4}	
• Technology			
<i>Diversification of farming system</i>	++	++	+
• Land lease		+	++
• Crop production		+	+
• Eco-tourism		+	
• Payment for ecosystem services (PES) from carbon and water			
<i>Increased farm or herd size</i>			
<i>Off-farm income</i>	++	++	
<i>Exiting pastoralism</i>	+++	++++	+

Notes: Technology: 1 = hay, 2 = ICT, 3 = local animal breeds, 4 = insurances, 5 = crop residue, 6 = agroforestry. Importance categories are: ++++ extremely high; +++ high; ++ moderate; + little.

Opportunities for intensification, diversification and off-farm income as well as strategic priorities for agricultural transformation are discussed in more detail for each of the three subsystems in Table 10.9 and in the sections below.

Needs that are common to the three subsystems include more secure access to grazing resources such as water and dry-season pasture; agricultural diversification; improved market information, marketing and value-adding of produce; and improved health services and education, including for women. However, implementation must differ between the three subsystems, due to their inherent differences in patterns of livestock mobility, human population, poverty, land use change and access to education and markets.

Table 10.9 Summary of the strategic priorities for agricultural transformation in the pastoral farming system

<i>Subsystem</i>	<i>Strategic priorities for agricultural transformation</i>	
	<i>Direct agricultural changes</i>	<i>System support to enable transformation</i>
Sahel	<i>Tenure security</i> , especially for land, and secure mobility and guaranteed access to critical resources such as water, grazing lands, saltlicks and dry-season pasture.	<i>Market orientation</i> , through: 1) better organization of pastoralists to strengthen bargaining power and increase access to regular market information, particularly for livestock prices; 2) the use of modern ICT techniques to enable pastoralists to obtain information directly from the market rather than to rely on intermediaries that limit pastoralists' returns from livestock sales; and 3) value-addition along the market chain to increase opportunities and returns from livestock.
	<i>Diversification of the farming system</i> , especially cropping and agropastoralism. This involves combining the production of crops and livestock as a means of minimizing risk due to climate change and variability, and as a strategy for food security.	<i>Diversification of income</i> , including increased share of off-farm income, commerce, remittances and other sources.
Eastern Africa	<i>Sustainable intensification</i> for increased productivity, through improved breeds with high quality and quantity of milk and meat.	<i>Technology interventions</i> that reduce risk of losing animals, such as livestock disease control and livestock insurance against drought.
	<i>Increase access to the natural resource base</i> , in particular tenure security of pasturelands and water.	<i>Value-addition</i> along the market chain to increase returns from livestock and livestock products.

	<p><i>Diversification of the farming system</i>, especially to engage in small-scale crop farming and leasing out land for large-scale commercial agriculture, ecotourism and provision of ecosystem services.</p>	<p><i>Enabling policies on livestock, natural resource management and related sectors, including security</i>, to promote land and resource tenure security, improve land use planning and management at national and regional level to allow for seasonal transboundary movements of herders and their livestock; enable improved security; establish or support institutions for peace building and conflict resolution and management of common pool resources; and promote disaster mitigation and response and climatic risk reduction and management.</p>
Southern Africa	<p><i>Increase feed availability and quality</i>, particularly in the dry season through identification and exploitation of alternative sources of feed such as byproducts from other agriculture systems.</p>	<p><i>Market orientation</i>, promoted through strengthening of livestock cooperatives for beef production and marketing; supporting cooperatives and collective actions to reduce the costs of inputs and enhance the understanding of market requirements; and reduce the role of speculators in the value chain.</p> <p><i>Technologies within existing ICT infrastructure</i> (e.g. mobile telephones) to increase information dissemination on input and output markets, and livestock traceability systems.</p> <p><i>Enabling policies</i> to allow and promote livestock mobility both within and across borders, ensure security of herders and their livestock, and support traditional institutions in conflict resolution and peace building.</p>

Sahel

The first and major priority is *securing pastoral mobility* for herders and their livestock. This can be achieved through adaptation of legal instruments (where necessary), legal support for herders and farmers in understanding and applying regulations, coordinated land management and pastoral infrastructure (water points, corridors and designated grazing area), and research with herder organizations on supply of livestock feeds (imported and local). A major concern in securing herd mobility is communal arrangements and infrastructure such as cattle paths, and setting aside rangeland and free access to water points. Increased size of and secure access to key resources, particularly water and pasture, are important prerequisites for livestock mobility and livestock-based poverty escape. The ECOWAS (Economic Community of West African States) agreement on livestock

mobility guarantees free movement across borders in the region, but it is being undermined by illegal levies charged by the police, army and the local government; the latter supports these charges under the guise of decentralization that empowers the local government to manage natural resources.

A second option is *diversification of the farming system*, especially into cropping and agropastoralism. This could combine the production of crops and livestock as a means of minimizing risk due to climate change and variability, and as a strategy for food security. To enable transformation in this subsystem, other strategic priorities are improved market orientation, resource tenure security and income diversification. While pastoralists increasingly grow crops, access to land and tenure insecurity remain major constraints to long-term investment in the land. Lastly, promoting off-farm income especially from commerce and remittances is critical because these are major sources of livelihood diversification for an increasing number of pastoral households, a trend that may persist. For those for whom the above options are not viable, exit from farming is the only pathway left.

Eastern Africa

The three main strategic priorities, in order of importance, are: *sustainable intensification*, for increased productivity through improved breeds with high quality and quantity of milk and meat production, which can be achieved through interventions that broaden the resource base such as hay harvest and storage; *increased size and secure access to the natural resource base*, in particular pasturelands and water; and *diversification of the farming system*, especially to engage in small-scale crop farming and leasing land for large-scale commercial agriculture, ecotourism and provision of ecosystem services. This requires educating pastoralists on appropriate farming techniques. Most critical, however, are land market regulations especially concerning large-scale land acquisition to mitigate potential negative outcomes for pastoral communities. To enable transformation in this subsystem, other strategic priorities are: (1) technology interventions including investments in physical and technological infrastructure, roads and ICTs to facilitate improved market access and information flow, and enhance disease surveillance and control to meet international sanitary and veterinary standards; (2) value-addition; (3) enabling policies on livestock, natural resource management and other sectors including security; (4) off-farm income and remittances, including commerce as pastoralists become involved in livestock and other trades; and (5) education to provide pastoralists with the knowledge and skills to gain employment in different sectors, better engage in livestock trading and invest in alternative livelihood activities.

Southern Africa

The top priority should be *to increase feed availability and quality* particularly in the dry season through exploitation of alternative sources of feed such as byproducts from agriculture systems. To enable transformation in this subsystem, other strategic priorities are: (1) market orientation especially to strengthen livestock cooperatives, particularly in the beef sector, to improve marketing; (2) supporting collective action processes, including collective herding at village level to reduce labour requirements and improve the utilization of the dwindling grazing resource base; (3) technologies within existing ICT infrastructure such as mobile telephones and RFID to increase information dissemination

on input and output markets, and livestock traceability systems respectively; (4) policy actions to enable livestock mobility, which is heavily restricted in the region due to strong regulations governing inter-country or between green and red (foot and mouth areas) zones within countries; and (5) strengthen security and collaborative resource management to reduce animal theft particularly on the borders of Lesotho and South Africa, and reduce communal conflicts over the ownership, use and management of grazing areas and watering points. Notably, security operations by government agencies should be complemented by platforms at grassroots level to facilitate the mutual sharing of boundary resources, given that where traditional institutions are strong there tends to be better management of grazing and water resources. Lastly, off-farm income, especially remittances, play a major role in sourcing of inputs such as veterinary medicines and supplementary feed for livestock. However, the relative contribution of these remittances is dwindling as the costs of direct human needs (food, medicines, education, etc.) are increasing rapidly.

System conclusions

The pastoral farming system performs reasonably well in terms of productivity with options for further productivity gains in milk and meat. The sustainability performance is more variable. While the returns per hectare are stable or may increase in part due to increased market orientation and higher offtake rates, there is a decline in livestock wealth and returns per capita. The Sahelian and the eastern African subsystems seem to perform poorly in terms of human development outcomes.

The various drivers of change affect pastoral livelihoods differently. Markets, technology, human capital and the development of pro-pastoral policies and institutions open opportunities for increased productivity, and can expand economic benefits from livestock and various livelihood diversification strategies. Population growth is reducing the average livestock numbers per household at a rate of 2.5 to 3 per cent per year, with effects on income poverty and wealth distribution. A lack of information on the rates of change of other drivers prohibits an assessment of their combined effect. While these positive drivers stimulate the economy of the pastoral farming system at large, it is questionable whether, for the average household, these positive drivers compensate for the effects of population growth.

The sustainable development goal (SDG) number 1 is to eradicate poverty by 2025. Agricultural intensification and exit from pastoral farming are the two most important pathways for pastoral households to escape from poverty. The first is a pathway for the better-off who are still in pastoral farming. The second is the involuntary choice of the stockless, landless, uneducated and unskilled.

For households still farming, pro-pastoral land use change and adoption of crop-based systems, including agropastoralism and irrigated cropping, are among the strategic interventions to reduce poverty in the pastoral farming system. Crop agriculture typically occupies the wetter lands, which are also crucially important for a vibrant pastoral farming system. Selectively changing the land use of these more productive patches of land marginalizes the livestock producers who are left with the less productive remnants, a process that has been occurring for a long time. This situation is further aggravated when pastoralists lose access to their traditional water resources in the converted lands. Addressing the social needs of pastoral communities through crop-based futures has implications for the productivity and resilience of the pastoral farming system. *Laissez faire* policies typically open opportunities for a happy few to acquire land for cropping and other non-pastoral

land uses at the expense of those left behind. These trade-offs are typically not considered. Better-integrated policies are required, and when embracing crop-based futures it is desirable to include all stakeholders in deciding the future of their land.

For pastoral dropouts, dedicated policies are required to support education and development of alternatives. The opportunities for livelihood diversification and off-farm income differ for the three subsystems.

Notes

- 1 Agriculture includes crop and livestock production.
- 2 A Tropical Livestock Unit is a 250 kg animal weight-equivalent index, which allows species of various weights to be combined.
- 3 NOAA National Oceanic and Atmospheric Administration of the United States.

References

- Aklilu, Y. and Catley, A., 2010. Livestock exports from Pastoral Areas: an analysis of benefits by wealth group and policy implications. *IGAD LPI Working Paper No. 01–10*.
- Ayantunde, A.A., Asse, R., Fall, A. and Said, M.Y., 2010. *Transhumance and endemic ruminant livestock in sub-humid zone of West Africa: contexts, concepts and challenges*. A synthesis report for the Global Environmental Facility (GEF) – Africa Development Bank (AfDB) project “Sustainable management of globally significant endemic ruminant livestock of West Africa”. International Livestock Research Institute (ILRI).
- Ayantunde, A.A., de Leeuw, J., Turner, M.D and Said, M., 2011. Challenges of assessing the sustainability of (agro) pastoral systems. *Livestock Science*, 139: 30–43.
- Barrett, C.B., 2005. Rural poverty dynamics: development policy implications. *Agricultural Economics*, 32: 45–60.
- Behnke, R., 2010. The contribution of livestock to the economies of IGAD member states: study findings. Application of the Methodology in Ethiopia and Recommendations for Further Work: IGAD (Inter-Governmental Authority on Development) Livestock Policy Initiative Working Paper No 02–10.
- Behnke, R.H., Scoones, I. and Kerven, C., 1993. *Range Ecology at Disequilibrium, New Models of Natural Variability and Pastoral Adaptation in African Savannas*. Overseas Development Institute, London.
- Bekure, S., de Leeuw, P.N., Grandin, B.E. and Neate, P.J.H. (eds), 1991. *Maasai Herding: An Analysis of the Livestock Production System of Maasai Pastoralists in Eastern Kajiado District, Kenya*. ILCA Systems Study 4. ILCA (International Livestock Centre for Africa).
- Blench, R., 1999. Why are there so many pastoral groups in Eastern Africa? In Azarya, V. (ed.) *Pastoralists Under Pressure? Fulbe Societies Confronting Change in West Africa*. Brill.
- Bouwman, A.F., Van der Hoek, K.W., Eickhout, B. and Soenario, I., 2005. Exploring changes in world ruminant production systems. *Agricultural Systems*, 84: 121–153.
- Breman, H. and De Wit, C.T., 1983. Rangeland productivity and exploitation in the Sahel. *Science*, 221: 1341–1347.
- Butcher, C., 1994. *Nomadic Pastoralism and Extension: A Review of the Literature*. Pastoral Development Network Paper 37d. www.odi.org.uk/odi.org.uk/files/odi-assets/publications-opinion-files/5407.pdf.
- Carr-Hill, R., 2005. *The Education of Nomadic Peoples in East Africa: Djibouti, Eritrea, Ethiopia, Kenya, Tanzania and Uganda*. Synthesis Report. International Institute for Educational Planning, UNESCO IIEP.
- Chantarat, S., Mude, A.G., Barrett, C.B. and Carter, M.R., 2012. Designing index-based livestock insurance for managing asset risk in northern Kenya. *Journal of Risk and Insurance*, 80: 205–237.

- Coppock, D.L., Desta, S., Tezera, S. and Gebru, G., 2011. Capacity building helps pastoral women transform impoverished communities in Ethiopia. *Science*, 334: 1394–1398.
- De Leeuw, J., Prins, H.H.T., Njuguna, E.C., Said, M.Y. and De By, R.A., 1998. *Interpretation of DRSRS Animal Counts (1977–1997) in the Rangeland Districts of Kenya*. ITC.
- De Leeuw, P.N., 1991. The study area: biophysical environment. In Bekure, S., De Leeuw, P.N., Grandin, B.E. and Neate, P.J.H. (eds) *Maasai Herding: An Analysis of the Livestock Production Systems of Maasai Pastoralists in Eastern Kajiado District, Kenya*. ILCA Systems Study 4, ILCA.
- De Leeuw, P.N. and Tothill, J., 1990. *The Concept of Rangeland Carrying Capacity in Sub-Saharan Africa: Myth or Reality*. ODI.
- Devereux, S., 2009. Why does famine persist in Africa? *Food Security*, 1: 25–35.
- Dixon, J., Gulliver, A. and Gibbon, D., 2001. *Global Farming Systems Study: Challenges and Priorities to 2030 – Synthesis and Global Overview*. FAO.
- Ericksen, P.E., de Leeuw, J., Thornton, P.K., Said, M.Y., Herrero, M. and Notenbaert, A., 2012. Climate change in Sub-Saharan Africa: what consequences for pastoralism? In Catley, A., Lind, J. and Scoones, I. (eds) *Pastoralism and Development in Africa: Dynamic Change at the Margins*, Routledge, pp. 71–81.
- FAO, 2001. *Pastoralism in the New Millennium*. FAO Animal Production and Health Paper 150.
- FAO, 2013. *Children's Work in the Livestock Sector: Herding and Beyond*. Economic and Social Development Department, FAO.
- FAOSTAT (undated) FAOSTAT database, FAO, Rome. www.fao.org/faostat/en/#data.
- Fratkin, E. and Smith, K., 1995. Women's changing economic roles with pastoral sedentarization: varying strategies in alternate Rendille communities. *Human Ecology*, 23: 433–454.
- Galvin, K.A., 2009. Transitions: Pastoralists living with change. *Annual Review of Anthropology*, 38: 185–198.
- Headey, D., 2011. *Deja vu in the Horn of Africa. 2011 Global Food Policy Report*. IFPRI, pp. 25–38.
- Hesse, C. and Cavanna, S., 2010. *Modern and Mobile: The Future of Livestock Production in Africa's Drylands*. IIED and SOS Sahel International UK.
- Homewood, K., 2004. Policy, environment and development in African rangelands. *Environmental Science and Policy*, 7: 125–143.
- Homewood, K., 2008. *Ecology of African Pastoralist Societies*. James Currey Ltd.
- Homewood, K., Kristjanson, P. and Trench, P., 2009. Staying Maasai? Pastoral livelihoods, diversification and the role of wildlife in development. In Galvin, K., Reid, R., Behnke, R. and Hobbs, N.T. (eds) *Fragmentation in Semi-Arid and Arid Landscapes: Consequences for Human and Natural Systems*. Springer, pp. 369–408.
- Lengoiboni, M., Bregt, A.K. and Van der Molen, P., 2010. Pastoralism within land administration in Kenya: the missing link. *Land Use Policy*, 27: 579–588.
- Lesnoff, M., Cormiaux, C. and Hiernaux, P., 2012. Sensitivity analysis of the recovery dynamics of cattle population following drought in the Sahel region. *Ecological Modelling*, 232: 28–39.
- Lesorogol, C.K., 2003. Transforming institutions among pastoralists: inequality and land privatization. *American Anthropologist*, 105: 531–541.
- Little, P.D., McPeak, J., Barrett, C.B. and Kristjanson, P., 2008. Challenging orthodoxies: understanding poverty in pastoral areas of east Africa. *Development and Change*, 39: 587–611.
- Lybbert, T.J., Barrett, C.B., Desta, S. and Layne Coppock, D., 2004. Stochastic wealth dynamics and risk management among a poor population. *The Economic Journal*, 114: 750–777.
- McPeak, J.G. and Barrett, C.B., 2001. Differential risk exposure and stochastic poverty traps among east African pastoralists. *American Journal of Agricultural Economics*, 83: 674–679.
- Moritz, M., Kyle, B.R., Nolan, K.C., Patrick, S., Shaffer, M.F. and Thampy, G., 2009. Too many people and too few livestock in west Africa? An evaluation of Sandford's thesis. *Journal of Development Studies*, 45: 1113–1133.
- Mwangi, E. and Ostrom, E., 2009. Top-down solutions: looking up from east Africa's rangelands. *Environment*, 51: 34–45.

- Nguyen, G.T., 1998. *Food Insecurity and the Evolution of Indigenous Risk-Sharing Institutions in the Sahel*. Ohio State University.
- Niamir-Fuller, M., 1999. Managing Mobility in African Rangelands. In McCarthy, N., Swallow, B., Kirk, M. and Hazell, P. (eds) *Property Rights, Risks and Livestock Development in Africa*. IFPRI, pp. 102–131.
- Nkedianye, D., de Leeuw, J., Ogutu, J.O., Said, M.Y., Saidimu, T., Kifugo, S., et al., 2011. Mobility and livestock mortality in communally used pastoral areas: the impact of the 2005–2006 drought on livestock mortality in Maasailand. *Pastoralism: Research, Policy and Practice*, 1(1): 1–17.
- Norton-Griffiths, M. and Said, M.Y., 2010. The future of wildlife on Kenya's rangelands: an economic perspective. In du Toit, J.T., Kock, R. and Deutsch, J.C. (eds) *Wild Rangelands: Conserving Wildlife While Maintaining Livestock in Semi-Arid Ecosystems*. Blackwell, pp. 367–392.
- Okwi, P.O., Ndeng'e, G., Kristjanson, P., Arunga, M., Notenbaert, A., Omolo, A., Henninger, N., Benson, T., Kariuki, P. and Owuor, J., 2007. Spatial determinants of poverty in rural Kenya. *PNAS*, 104: 16769–16774.
- Osano, P., 2013. Payments to promote biodiversity conservation and the implication for poverty reduction among pastoral communities in east African arid and semi-arid lands. PhD Thesis, Department of Geography, McGill University.
- Osano, P., Said, M., De Leeuw, J., Moiko, S., Kaelo, D., Schomers, S., Birner, R. and Ogutu, J.O., 2013. Pastoralism and ecosystem-based adaptation in Kenyan Maasailand. *International Journal of Climate Change Strategies and Management*, 5(2): 198–214.
- Perry, B. and Grace, D., 2009. The impacts of livestock diseases and their control on growth and development processes that are pro-poor. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1530): 2643–2655.
- Pike, I.L., 2004. The biophysical consequences of life on the run: a case study from Turkana district, Kenya. *Human Organization*, 63: 221–235.
- Pretty, J. and Ward, H., 2001. Social capital and the environment. *World Development*, 29(2): 209–227.
- Prothero, R.M., 1994. Forced movements of population and health hazards in tropical Africa. *International Journal of Epidemiology*, 23(4): 657–664.
- REGLAP, 2012. *Good Practice Principles on Community Development for Use in Disaster Risk Reduction in the Drylands of the Horn of Africa*. REGLAP, Nairobi.
- Ruppert, J.C., Holm, A., Mieke, S., Muldavin, E., Snyman, H.A., Wesche, K., et al., 2012. Meta-analysis of ANPP and rain-use efficiency confirms indicative value for degradation and supports non-linear response along precipitation gradients in drylands. *Journal of Vegetation Science*, <http://onlinelibrary.wiley.com/doi/10.1111/j.1654-1103.2012.01420.x/pdf>.
- Sadler, K., Kerven, C., Calo, M., Manske, M. and Catley, A., 2009. *Milk Matters: A Literature Review of Pastoralist Nutrition and Programming Responses*. Feinstein International Center.
- Sheik-Mohamed, A. and Velema, J.P., 1999. Where health care has no access: the nomadic populations of sub-Saharan Africa. *Tropical Medicine & International Health*, 4(10): 695–707.
- Slegers, M.F.W. and Stroosnijder, L., 2008. Beyond the desertification narrative: a framework for agricultural drought in semi-arid east Africa. *AMBIO – A Journal of the Human Environment*, 37: 372–380.
- Sperling, L. and Galaty, J.G., 1990. Cattle, culture and economy: dynamics in east African pastoralism. In Johnson, L.D. and Galaty, J.G. (eds) *The World of Pastoralism: Herding Systems in Comparative Perspective*. Belhaven Press, pp. 69–98.
- Swift, J., 1988. *Major Issues in Pastoral Development with Special Emphasis on Selected African Countries*. FAO, Rome.
- Toure, I., Ickowicz, A., Wane, A., Garba, I. and Gerber, P. (eds), 2012. *Atlas des évolutions des systèmes pastoraux au Sahel*. FAO and CIRAD.

- Turner, M.D., Ayantunde, A.A., Patterson, K.P. and Patterson, E.D., 2011. Changing access to resources, social identity, and farmer-herder conflict in Sahelian west Africa. *Journal of Developments Studies*, 47(2):183–206.
- Vrieling, A., de Leeuw, J. and Said, M.Y., 2013. Length of growing period over Africa: variability and trends from 30 years of NDVI time series. *Remote Sensing*, 5: 982–1000.
- Watkins, K. and Alemayehu, W., 2012. *Financing for a Fairer, More Prosperous Kenya: A Review of the Public Spending Challenges and Options for Selected Arid and Semi-Arid Countries*. Brookings Institution.
- Zwaagstra, L., Sharif, Z., Wambile, A., de Leeuw, J., Said, M.Y., Johnson, N., Njuki, J., Ericksen, P. and Herrero, M., 2010. *An Assessment of the Response to the 2008–2009 Drought in Kenya*. A report to the European Union Delegation to the Republic of Kenya. ILRI.

11 The fish-based farming system

Maintaining ecosystem health and flexible livelihood portfolios

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Key messages

- The fish-based farming system occupies the edges of Africa's water bodies along coastlines, lakeshores and the floodplains of river systems and provides a diversified, flexible and resilient livelihood portfolio for some 22 million sub-Saharan fisher-farmers with half of those living in extreme poverty. The fisheries operations provide 30 to 50 per cent of household income.
- System performance is under threat from land use changes that affect the quality, quantity and timing of the water supply, notably deforestation and the construction of dams upstream but also conversion to large-scale irrigation. On coasts overfishing is an issue.
- Maintaining the drivers of ecosystem productivity and especially the natural flooding regime is crucial. Governance inspired by traditional systems with strong involvement of the users in all stages of planning and management will facilitate development trajectories that are adapted to local context, favouring incremental rather than wholesale change.

Summary

The fish-based farming system encompasses mixed fishing/farming households that derive from 30 to 50 per cent of their income from fisheries and engage in a wider livelihood portfolio including forestry, livestock production, hunting and gathering. It covers a range of ecosystems, climatic zones and sociopolitical contexts. The majority of rural households in the system engage in small-scale fishing, especially young men using canoes and gill nets, but women and children also operate on foot. Fisheries can still be regulated by traditional institutions, but the trends are towards ineffective, state-based regulation or free-for-all situations. Externally financed, larger-scale operations at greater distances from the farm are on the rise.

Fishery productivity is largely dependent on the flood pulse linked to seasonal rainfall patterns. Deforestation, land degradation and weather extremes are creating unfavourable, sharper and shorter flood peaks. River regulation by dams decreases system extent and productivity. Trends are towards declining recession agriculture, pasture production and fish reproduction. Large-scale irrigation systems tend to replace the system and exclude its original beneficiaries.

Understanding of the system's functional requirements and its wide-ranging benefits is scanty in both government and development agencies, and thus some pessimism about its future is justified. Emphasis has been on extracting more from the system through industrialisation and upscaling, including for export, but failures are rife. Less attention has been directed to maintaining and enhancing system productivity through ecosystem management interventions, and facilitating the small-scale fisher-farmer's operations through co-management. The absence of an enabling environment and heavy local taxation favours self-sufficiency rather than marketing.

Maintenance of the structural and functional integrity of the wetland ecosystems should be a key focus, especially maintaining the flood pulse, including through managed flood releases from dams. Co-management, based on traditional governance systems, has a better chance of effectively banning destructive techniques and safeguarding nursery areas and reproductive seasons. There is a need for jointly analysed and agreed interventions, more flexible mesh-size regulations suited to local conditions, irrigation systems designed to add to the natural system, and maintenance of input-effective recession agriculture and other flood-based biodiversity, ecosystems and livelihoods. Given climate change uncertainties, planning must include wide error margins for floodplain infrastructure.

Aquaculture production is rapidly expanding. The introduction of inappropriate species should be avoided. Emphasis should be on fish that are low in the food chain (e.g. tilapia) and also on the preservation of the natural systems and existing water bodies. Small-scale testing, incremental technological improvements and household level roll-out may be the more sustainable and equitable approach. Culture of the ubiquitous, oil-rich and nutritious catfish *Clarias gariepinus*, which survives in almost any habitat and is the perfect fish to be smoked, offers opportunities using simple village ponds seeded from the wild.

Much can be learned from projects initiated by non-governmental organisations, but interventions should preferably be embedded in local government and operate over medium-scale timeframes. Support through holistic (non-sectoral) and non-dogmatic rural extension workers with a thorough understanding of the local context should be prioritised. Options for governance reform determined via multi-stakeholder dialogue and considering evidence, livelihood security, human rights and cross-sectoral and cross-scale interactions need to be explored.

Introduction

Fishing is an ancient human activity, much older than agriculture, and has probably been a key part of what made us a successful species. Dug-out canoes are known from the Lake Chad basin in 9000 BP, and bone harpoons and hooks of similar age are found in many areas in the formerly wet Sahara and Sahel.

The fish-based farming system encompasses mixed fishing/farming households – the fisher-farmers tend to have a flexible and opportunistic livelihood portfolio that, besides farming and fishing, includes livestock, forestry, hunting, gathering and often occasional wage-earning (Box 11.1). The question as to whether the people on Lake Victoria's shores should be designated as 'farming fishermen' or 'fishing farmers' (Geheb and Binns 1997) illustrates that livelihoods in Africa can combine the best of both worlds, terrestrial and aquatic. For this system, full household livelihood spectra have rarely been assessed, and accurate estimates are hard to come by as the system is mostly linear in nature, stretching along coastlines, lake shores and rivers in a 50 km wide strip that is not generally considered as an administrative or statistical unit. In the floodplains of the Zambezi

Figure 11.1 The basic production unit of hundreds of thousands of sub-Saharan fishers: a dugout canoe, a paddle and a gill net in the Tana delta floodplain, Kenya.

Source: Olivier Hamerlynck.

(Turpie et al. 1999) and the Rufiji (Turpie 2000) the majority of the farming households derive from 30 to more than 50 per cent of their income from fisheries.

Fishing is generally practised in close proximity to the household farm. As the farming part of the system is treated in other chapters, this chapter emphasises the fisheries aspects. The chapter focuses on smallholders and does not address the full-time fishers that are disconnected from farming for most of their lives or fish away from home for extended periods. These are not part of the system but may easily move in (and back out) for varying time periods.

A large proportion of farming households in proximity to large and small water bodies engage in small-scale fishing often temporarily (occasionally, seasonally or in a specific age class – most commonly young men). The basic fishing unit consists of a dug-out canoe, a nylon net and a paddle (Figure 11.1). The low capital cost of the tools partly explains the flexibility with which farmers can engage in fishing, to procure high protein content food (plus essential vitamins, fatty acids and oligo-elements) for consumption or to obtain immediate cash for social needs such as school fees (Paul et al. 2011) and medical care. In shallow water bodies, fish are also obtained on foot by women and children using mosquito nets or woven baskets. There is a trend towards externally financed fishing operations on a larger scale (larger vessels with engines and bigger nets) where fisher-farmers become employees and quit farming, at least seasonally. These individuals move out of the system but the rest of the household remains in the system.

Overall description of the system and subsystems

The fish-based farming system, stretching along the African coastline and across its centre (Figure 11.2), occurs in a wide range of climatic zones and ecosystems. Average length of growing period (LGP) ranges from basically zero on the desert fringes to the entire year near tropical water bodies. The subsystems have many similarities with the neighbouring farming systems described in other chapters, but they also have some characteristics that set them apart. The proximity of large bodies of water, the oceans lapping sub-Saharan Africa's rim, the Great Lakes in the Rift Valley and the large floodplains along some of Africa's main rivers, create conditions such as increased rainfall, reduced evaporation from cloud cover and comparatively abundant surface- and groundwater that lift LGP constraints.

Figure 11.2 Map of the fish-based farming subsystems; note the linear shoreline nature of the system, bordering a wide range of farming systems especially mixed maize, agropastoral, pastoral, tree crop, forest-based and irrigated.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Box 11.1 Typical smallholder farm household profile in the fish-based farming system

Juma and Fatima are in their twenties and have three children. Juma's mother is also part of the household and neighbours in need (e.g. a widow and her children) often share the meals. The family owns a cow, a dozen chickens and three goats, and cultivates two small plots totalling 1.25 ha, one close to the house (0.25 ha) with some tree crops (coconut, cashew, mango, banana), beans and oilseeds, the other (1 ha) in a flood-prone area where they intercrop rice, their preferred staple, with maize. An alternative would be sorghum in drier valleys such as the Senegal and the Niger. Yields are in general below 1 t/ha but can reach 1.5 to 3 t/ha for rice. There is no need for inputs nor much weeding and, in good years, they are self-sufficient.

During the planting and harvesting season Juma puts out a gill net at night in the adjacent lake and, after the flood, he also fishes with a friend during the day using a rented canoe.

In unfavourable years, he joins a team in the forest to cut trees and saw them into planks. Alternatively he can join an expedition for illegal fisheries or ivory poaching in an adjacent protected area to mobilise cash for school fees. He also does odd jobs such as road maintenance, school building or census work whenever the opportunity arises.

Basic data in Table 11.1 describes the sub-Saharan part of the farming system as displayed in Figure 11.3 and excludes the North African fish-based subsystem areas found in Egypt (Figure 11.2) for which data was not readily available. Table 11.1 and Figure 11.3 also do not include the floodplain fish-based subsystem, which is only indicated for illustration purposes in Figure 11.2.

The fish-based system covers an estimated 3 per cent of sub-Saharan Africa and is home to about 4.2 per cent of its agricultural population, that is some 22 million people, of whom about 50 per cent subsist in extreme monetary poverty (less than US\$1.25 a day). In addition, of that surface area, about one-third is uninhabited water body, so rural population density is quite high at 50 inhabitants per km². The system also typically contains large and rapidly growing urban centres, with a population three times that of the rural areas.

Most fish-based farming subsystems have fast population growth rates (e.g. 3.3 per cent over the past 50 years around Lake Victoria) in comparison with the less well-watered surrounding areas. These high growth rates are partly explained by immigration, especially in areas where the fish-based farming system has established itself around newly created artificial lakes (dam reservoirs).

An obvious difference between fishing (or hunting) and livelihoods dominated by farming or livestock keeping is that there is a cash return on a daily basis as well as a dependable supply of animal protein. With water serving as a transport medium, markets are on average five hours away. This is almost half of the time needed by the dominant, adjacent farming systems.

The situation is complex and variable across the fish-based farming subsystems. In general, rural livelihoods in proximity to large water bodies (temporary or permanent)

Table 11.1 Basic system data (2015): fish-based farming system

Item	Data
Total human population (million)	102.2
Agricultural population (million)	21.6
Total area (million ha)	74.7
Cultivated area (million ha; % of total area)	4.8; 6
Irrigated area (million ha; % of cultivated area)	0.65; 13
Total livestock population (million TLU)	41.7
Major agroecological zone	Tropical warm subhumid
Length of growing period (average, days ; core range, days)	194; 150–330
Access to services (low/medium/high)	Medium-high
Distance to 50k market (average, hr; core range, hr)	5.0; 2–10
Agricultural population density (persons/total area; persons/cultivated area)	0.3; 4.5
Livestock density (TLU/total area; TLU/cultivated area)	0.6; 8.6
Standard farm and herd size (cultivated area/household; TLU/household)	1.2; 10.6
Extreme poverty (% of rural population)	48

Source : Refer to Table 2.4.

Note: Basic data refer to the sub-Saharan African portion of the farming system.

show a high degree of occupational flexibility in response to changing circumstances and climatic events and, because of the low capital outlay of the basic fishing operation (canoe, paddle, nylon net or even a mosquito net or a reed basket), which can be owned, rented or borrowed, and the low level of skill required, entry or exit from the fishery is easy. Many fishers will only practise this comparatively risky activity (hippos, crocodiles, sudden storms) during a particular time of their lives (e.g. before they have access to land), or seasonally (during or after extensive flooding). As a passive, low intensity activity (setting the nets in the evening, hauling them in in the morning), fishing is easy to combine with a multitude of resource-harvesting or income-generating occupations. The basic economic unit is the household (or even the extended family), and though some individuals may focus more on fisheries, the other members of the unit will predominantly farm.

Small-scale fisheries are known to be high employment multipliers generating land-based jobs. The multiple contributions of fishing to human well-being¹ are rarely captured in sectoral statistics – which tend to concentrate on formal, industrial fisheries operations and are notoriously unreliable for small-scale fisheries (De Graaf et al. 2011) – and macro-economic accounting (Béné et al. 2010a).

Some ethnic groups still derive their identity from fisheries (e.g. the Bozo on the Niger River). In other societies fishing is restricted to certain castes, but the trend is towards livelihood diversification (Ellis 1998) with both fishing and livestock keeping becoming an integral part of the portfolio in traditional ‘farming’ families and vice-versa.

The basic unit in the system remains the dugout canoe or two canoes operating a larger net together. Increasingly, groups of fishers using longer nets will work from bigger vessels with or without outboard or inboard engines, especially on the coast and in lakes. Thus, there can be a gradual (often seasonal) or total disconnect between farming and fishing with fishing becoming a full-time, lifelong, salaried activity in the employ of

Figure 11.3 Map of the fish-based farming system in sub-Saharan Africa.

a town-based owner/operator or as a member of a collective organisation (e.g. in west Africa). The borders between the fishing-farming system and other livelihood spectra are therefore highly porous. The presence of high added-value species (e.g. groupers, snappers, Nile perch, shrimp, crabs, rock lobsters, octopus or sea cucumbers) for export or for local tourist resorts facilitates the move to full-time fishing. Such areas (coast, lakeshores) typically have high population densities and a scarcity of productive land, which reduces farming opportunities, and thus large numbers of fishers competing for few fish. So, in spite of a potentially high value catch, most of these fishers still live a 'hand to mouth' existence and can resort to desperate and unsustainable strategies such as dynamite fishing on coral reefs, the use of poisons or large seine nets, often owned by investors for whom the fishers are just low-paid manual workers. With high catches and good money generated in outlying camps where the normal household structure is absent, much of the proceeds may be spent on alcohol, drugs and female company, making these areas prone to high HIV-AIDS incidence (Seeley and Allison 2005).

Often, when fisheries' productivity in proximity to the household farm is in decline, migration to richer grounds will occur lasting several weeks or months (Nunan 2010) with high demand from urban centres a major driver. These migrating fishers compete with the local fisher-farmers and, because the migrants often use less selective or more destructive fishing or fish processing techniques, this can lead to conflict.

There are five main subsystems defined by the characteristics of the water bodies fished, whether salty or fresh water, as well as the dominant substrate type (hard, coral, sandy, muddy, mangrove) (Figure 11.2). Aquaculture can be combined with each of the subsystems.

The coastal fish-based systems can be subdivided into two main subsystems: (1) the coral reef coast fish-based subsystem and (2) the sandy coast fish-based subsystem. The freshwater fish-based systems can be subdivided into: (1) the lake fish-based subsystem and (2) the floodplain fish-based subsystem. The brackish water, mangrove and estuarine deltaic fisheries is named the deltaic fish-based subsystem.

Coral reef coast fish-based farming subsystem

This subsystem stretches from southern Somalia to southern Mozambique and along the shores and islands of the western Indian Ocean (including the western and northern coasts of Madagascar), as well as in the Red Sea.

On the Swahili coast all manner of traditional vessels, from tiny dugout canoes (Figure 11.4) to larger vessels, can be seen leaving the beaches or coves at sunrise, setting out to fish on inshore or off-shore reefs. They use a plethora of active and passive gear, including hand lines, baited baskets, gill nets, seine nets and spears. On calm, moonless nights lights are used to attract small pelagics and post-larval reef fishes but also the larger predatory fish

Figure 11.4 Coral reef fishing operation using traditional baskets that are set close inshore (Tanga, Tanzania).

Source: Olivier Hamerlynck.

hunting the small ones. Fishing is mainly practised during the northeast monsoon season ('Kaskazi' – November to March) with moderate winds and a calm ocean. During the main rains (March to May), fishers shift to agricultural activities. During the southeast monsoon ('Kusi' – June to September), strong winds and waves restrict fishing.

In addition to boat-operated fisheries, a very important livelihood activity is the gleaning on foot of exposed reef flats at low tide, in particular during spring tides. This fishery targets a range of aquatic species, e.g. sea cucumbers that are dried and exported to Asia (Eriksson 2012), molluscs (cephalopods such as octopus, and gastropods both for consumption and for trade in sea shells) and crustaceans that are dislodged from under rocks as well as a range of creatures used as bait for the canoe-based fisheries. While finfish fisheries are an almost exclusively male activity, women and children are involved in reef-flat fisheries. On easily accessible reefs this can lead to a rapid depletion of the various resources (Andrefouet et al. 2013). The capture of live coral fish for the aquarium trade has not really taken hold in the western Indian Ocean. Similarly, aquaculture of crustaceans and fish is low technology and small-scale, and the existing operations remain entirely dependent on wild-caught seeding animals or fattening of wild-caught crabs.

Much of this farming subsystem has replaced lowland coastal forest, one of the planet's richest and most threatened biodiversity hotspots (Myers et al. 2000), leaving only small 'sacred' groves (Robertson and Luke 1993) and a few protected areas. Initially the soils are productive but gradually, with nutrients taken up by crops and leached out by rain, they become poor. Maintaining productivity requires adding and retaining nutrients, preferably by mulching and adding animal dung in principle available from the comparatively trypano-tolerant Zebu cattle and small ruminants typical of this subsystem.

Figure 11.5 High density of reef fishes in Mafia Island Marine Park, Tanzania.

Source: Olivier Hamerlynck.

Coral reefs are highly diverse (Figure 11.5) and among the most valuable ecosystems on earth, providing a range of ecosystem services (De Groot et al. 2012) but vulnerable to a range of direct and indirect drivers of change, few of which are currently being adequately addressed.

Sandy coast fish-based farming subsystem

Sandy coasts occur all along Africa's Atlantic shores from Morocco down to southern Senegal (the Siné-Saloum) where the mangrove systems take over. Just east of Sherbro Island in Sierra Leone they dominate again down to the Cape of Good Hope (where rocky shores predominate). Then there are sandy coasts again along the southern shores of the western Indian Ocean north to Mozambique where coral reefs and coastal mangrove systems take over until the upwelling areas along the Somali coasts (at about 7°N).

These coasts are highly dynamic with strong wave action and violent rip currents, which pose a challenge to fisheries using small craft. They are also characterised by upwelling of nutrient-laden, cold water leading to high productivity. Upwelling is strongest on the coasts of Mauritania, Namibia and Somalia. Upwelling is more variable in the Gulf of Guinea but still an important driver of fisheries productivity. Strong upwelling attracts some of the most sophisticated and powerful trawlers on the planet. Hundreds of thousands of tonnes of mainly pelagic fish are caught, either through licensing agreements with the coastal nations or illegally. Such vessels also "stray" into inshore waters, in theory reserved for small-scale fisheries.

The motorised canoe-based fisheries initially developed in Ghana (Akyeampong 2007) and spread to Sierra Leone and all the way to northern Angola. The technology was adopted and adapted further north in Senegal and Mauritania.

With its spread along the African coasts, the subsystem covers many different climate zones, rainfall regimes and livelihood practices. In the areas fringing on the Sahara fisheries are combined with mobile livestock keeping. In northern Senegal fisher-farmers practise market gardening (vegetables), further south they farm millet and groundnuts ('le bassin arachidier'). Other variations occur in the cereal-root crop, the root and tuber crop, tree crop and the forest-based systems.

In west Africa, starting from the 1980s after the failure to establish local industrial fisheries, there was a strong expansion of motorised fisheries using 'pirogues' (Figure 11.6); these are modified from river canoes to resist the strong wave action and pass the sandbars on the windswept sandy beaches. When local stocks declined the fisheries migrated to richer waters, first seasonally but increasingly through permanent settlements (Chauveau and Jul-Larsen 2000). From Senegal, the migrant fisheries expanded north to the western Sahara and southward into the deltaic fisheries areas. From Ghana they expanded westward to Ivory Coast and eastward to Nigeria and Cameroon, and from Benin to the Congo (Marquette et al. 2002) and Angola.

West Africa is characterised by migrations and dynamic livelihood strategy shifts (Njock and Westlund 2010). Coastal people as well as sedentary farmers from the Sahel have moved to the cacao growing areas and other plantations or to the oil-producing nations. Former desert nomads and traders from the Sahara opened shops and businesses in the fast-growing urban centres along the coast. Floodplain dwellers from the Inner Delta of the Niger have become the predominant fishers of the lagoon systems of Ivory Coast. Statistics on life-history trajectories are notoriously hard to come by, but it is thought that only about 10 per cent of the west African artisanal² fishers engage in fishing as a full-time, life-long activity

Figure 11.6 The settlement of Guet N'dar in the Senegal River Delta dates back to the eighteenth century. It is home to thousands of fishers who migrate all along the west African seaboard and catch some 30,000 tonnes annually. Trucks from many countries come there to load cheap pelagic fish while the expensive bottom-living fish and prawns are flown to Europe.

Source: Olivier Hamerlynck.

and produce 90 per cent of the catch (Chauveau and Jul-Larsen 2000). These are not considered part of the fishing–farming system. The vast majority of fishers will practise farming or, especially those who have fisheries associated skills (e.g. engine maintenance), move into other economic activities (e.g. transport) seasonally, temporarily or permanently.

Typically women, though excluded from boarding the pirogues, dominate the processing and marketing part of the fisheries (Bennett 2005). Especially in Ghana (the famed ‘Mama Benz’ after their preferred vehicles, the Mercedes³), this has evolved into the pre-financing of fishing operations (equipment, fuel, gear) to secure privileged access to the catch.

Artisanal fisheries provide crucial cheap protein to the populations of the west African sub-region. The migrant fleets often compete with sedentary locals and with the mostly foreign-based industrial fisheries targeting the same stocks (Atta-Mills et al. 2004). West African artisanal fisheries have now developed to a level where overfishing occurs, especially of more long-lived bottom-dwelling fish for export. However, our understanding of the dynamics of the food chain in these systems and of the drivers of ecosystem change (upwelling, the different fisheries) is limited. It is advisable to regulate access and gear use as well as secure nursery and reproduction areas through Community Conserved Areas or Marine Protected Areas, preferably based on collective action and traditional management systems.

Lake fish-based farming subsystem

The shores of the African lakes along the branches of the Great Rift Valley present highly varied landscapes – from the small high altitude Ethiopian lakes to the giant, desert Lake Turkana, the lush green papyrus swamps of Lake Victoria, the oil palm plantations on the sandy rims of northern Lake Tanganyika and the rocky shores of its more southerly parts, and the lower rainfall, Baobab savannahs by Lake Malawi. The lakes often have a highly diverse fish fauna whose complex biogeography is linked to ancient connections with the Nile, low water level periods with isolation as well as species introductions. The fisheries in these lakes have a wide range of socioecological contexts and generalising across them is a challenge. It should be noted that, as was the case for the sandy shore fisheries, attempts at industrialisation in Lakes Victoria, Tanganyika and Malawi by the introduction of trawlers have been largely unsuccessful. Since the 1960s fisheries have been rapidly expanding in all these areas and are now practised by hundreds of thousands of people in the lakes and dam reservoirs, especially night-time fishing for small pelagics using lights. There is a trend towards full-time fishing as employees of companies, but many are still fisher-farmers.

The Lake Victoria fisheries are the subject of highly controversial and often ideological debates with contradictory interpretations of ecosystem changes, overexploitation and impacts on human well-being. The dominant discourse is that overfishing is the major threat to the Lake Victoria fisheries, but detailed analysis does not seem to confirm this (Kolding et al. 2008). In 1960, an estimated 10 million people lived within 100 km of the shores of Lake Victoria. Currently this is probably over 50 million and still highly dynamic, doubling every 22 years and with at least 1.5 million depending directly on the lake fisheries (some 200,000 fishers operating from about 50,000 boats plus the associated land-based jobs). Population density is among the highest in rural Africa with over 200 inhabitants per km² in the Kenyan and Ugandan sectors (Odada et al. 2004). At the same time the fishery has developed exponentially in spite of spectacular changes in species composition.

The fishery targeting the introduced Nile perch is largely (about 75 per cent) destined for export and is an important source of income for local fishers, even though most of the added value profits the fish traders, export companies and supermarket chains that sell the fish abroad (Béné et al. 2010b). Three other species, whose consumption is predominantly African, are important: the introduced Nile tilapia (*Oreochromis niloticus*) which is a 'middle-class' food for city dwellers, the small freshwater shrimp *Caridina nilotica*, which is converted to fishmeal and, most significantly, the 500,000 tonnes of the tiny (maximum 10 cm) pelagic silver cyprinid *Rastrineobola argentea*. This species is sundried and exported throughout eastern and southern Africa for human consumption but also converted to fishmeal for animal feed, including aquaculture. With similar small pelagics caught in Lakes Tanganyika (Mölsä et al. 1999) and Malawi (Weyl et al. 2010), the cyprinid is a major source of cheap protein for vulnerable people over a vast area. It is hard to overstate the impact even small quantities of fish protein and fatty acids can have on human well-being, especially for children.

Productivity of lakes and reservoirs used to be thought of as determined only by the static variables depth and dissolved solids. Increasingly, fluctuations in water level are thought to play a significant role (Kolding and Van Zwieten 2012). As is the case in floodplains, freshwater pulses linked to rainfall bring additional nutrients from run-off, and the higher water level will flood vegetated shorelines to provide suitable habitat for fish to spawn as well as provide the juveniles with abundant food and reduced predation.

The farming system with which the fishery combines is determined by rainfall and LGP along the north–south gradient. Pastoral systems dominate around Lake Turkana and crops are restricted to the deltas of inflowing rivers. In the highland perennial system around the shallow and productive Lake Victoria plantains feature prominently in the landscape and in the diet. Further south, in the drier maize mixed system around the deeper and stratified large lakes such as Lakes Tanganyika and Malawi, farming opportunities are rainfall constrained. Fishing–farming systems also exist around innumerable smaller lakes and the reservoirs of hydropower dams, although, for the latter, productivity is comparatively low, except during the initial boom linked to the nutrient inputs from the dying terrestrial vegetation as the dam is filled. The smaller Rift Valley lakes are in general alkaline, which limits their productivity.

A relatively new type of this subsystem is developing around the reservoirs of hydropower dams, which form new lakes such as Lake Volta (Zwieten et al. 2011) and Lake Kariba (Tweddle 2010). These have attracted migrant fishers in west Africa from the Niger River Inner Delta, for whom it is a profitable, seasonal switch from the floodplains. Poverty in the fishing communities of Lake Volta relates to a wide range of non-fisheries-related socioinstitutional factors, including land ownership, debt, access to health, education and financial capital as well as marginalisation from political decision making (Béné and Friend 2011).

Floodplain fish-based farming subsystem

Because of the strong seasonality of rainfall, most large river systems in Africa have extensive floodplains (Table 11.2), covering over 300,000 km². In west Africa some of these floodplains, such as the Niger River Inner Delta in Mali and the Senegal Valley, have been intensively fished, grazed by livestock and farmed, probably for millennia, and have developed ‘tribes’ (e.g. Bozo and Somono) or castes (Subalbe – in fact a Fulani ‘non-caste’) specialised in fisheries. They have relatively high population densities in comparison with the neighbouring arid and semi-arid lands and are true fish-based farming systems with strong interactions with both agropastoral and irrigation farming systems. Other floodplains, such as the Congo River system, are more or less inaccessible and have low population densities (Béné et al. 2009) and considerable potential for expansion.

Table 11.2 Main African river basins and their floodplain systems with an estimate of their extent in km²

<i>Major river basins</i>	<i>Extent (km²)</i>	<i>Floodplain basins</i>
Nile basin	93,000	Sudd, Kagera
Congo basin	70,000	Middle Congo depression, Kamulondo, Malagarasi
Lake Chad basin	63,000	Chari and Logone River system
Niger/Benue basin	38,900	Niger central delta, Benue River
Zambezi basin	19,000	Kafue flats, Barotse plain, Liuwa plain
Western basins	19,000	Floodplains along the Senegal, Volta and Ouémé
Eastern basins	9,270	Kilombero, Rufiji, Tana
Southern basins	7,500	Okavango, Pongolo, Limpopo

Source: Modified from Tockner and Stanford (2002).

Figure 11.7 Migrating Bozo fishers in the Faguibine system in Mali with one donkey cart to move the canoe, the other for the gear, camping equipment, food, firewood and the family.

Source: Olivier Hamerlynck.

In the vast Sudd marsh on the Nile in South Sudan data is scant because of decades of insecurity. Still others are inside protected areas and therefore uninhabited or, as the Okavango Delta, advertise themselves as ‘untouched’ by humans and are primarily high-end, wildlife-viewing destinations, even if traditional fishing (Mmopelwa and Ngwenya 2010), recession farming and mobile livestock keeping also occur. So, in many large and small floodplains mixed livelihoods are practised but on a scale and by groups of people who tend to be invisible in the national statistics.

African floodplain fish-based farming subsystems are strongly seasonal environments with little scope for full-time, lifelong fisheries-only livelihoods unless migration to areas with inverse seasonal dynamics is an option. Thus Bozo fishers from the Niger River Inner Delta (flood peak in November) move to the neighbouring Faguibine (flood peak in March) system (Figure 11.7, Box 11.2); others will fish seasonally in dam reservoirs such as Manantali.

The key characteristic of these systems is their regular seasonal flooding. Floods, in spite of their negative reputation, are actually the engine in system productivity. Local user communities perceive them positively (Duvail and Hamerlynck 2007) and understand the many ecosystem services that they provide, such as groundwater recharge (allowing recession agriculture), deposition of fertile silt, productive fisheries with on average 40 to 60 kg of fish caught per ha flooded per year (Welcomme 2008) and the development of pasture that will take wild and domesticated herbivores through the long dry season.

Recession agriculture (Box 11.2) is often the dominant activity complemented by a wide range of alternative livelihood strategies (Béné et al. 2003; Turpie 2000). Fishing is alternated with other activities, including agricultural work such as clearing, hoeing, sowing and harvesting, often in intricate calendars that can also show strong inter-annual variation depending on rainfall and floods.

With population expansion into marginal areas, an increasing number of temporary water bodies that used to be reserved for seasonal grazing and watering of animals are now permanently settled, often by marginal groups such as liberated serf castes in the Sahel. Livelihoods there combine recession farming, small-scale irrigation, market gardening and fishing or even low-intensity forms of aquaculture (seeding the water body with catfish and/or ‘tilapia’ fry).

Figure 11.8 Floodplain farming in Rufiji, Tanzania (photo taken from a cashew tree). The maize is intercropped with rice in the deeper parts of the naturally flooded depression. Both the chicken coop and the house are on stilts.

Source: Jean-Luc Paul.

In the wetter areas with access to denser woody vegetation (wooded grasslands, woodlands and forests) these livelihoods can be further expanded with timber and non-timber forest products, such as wild food gathering including bush meat (Brashares et al. 2004), honey gathering or production, traditional medicine, pole cutting, charcoal production and logging. Permanent tree crops such as banana, cashew and mango can also play an important role in these systems.

Because of the generally low predictability and high variability in these systems (timing and abundance of seasonal rainfall, timing and extent of flooding) resource use strategies, crop choices and timing of planting are often highly opportunistic and oriented towards risk avoidance.

Thus, in floodplain systems, each household will clear and plant several plots (often less than a hectare), situated at a different elevation and on varying soil types. These plots are intercropped for example, rice interspersed with maize (Figure 11.8), often using both fast- and slow-maturing varieties. By sowing over a range of dates linked to rainfall events they hedge their bets under different flood (height and duration) and rainfall scenarios in the hope that at least one crop in one plot will provide sufficient starch for subsistence. Should everything sowed or planted be washed away, the fisheries – which are highly productive after an intense flood pulse – will be the immediate alternative followed by the planting of recession crops such as pumpkins that thrive under conditions of high soil moisture, groundwater recharge and the deposition of fertile loam and clay by the flood. By their very nature these floodplains usually have comparatively low population densities, and certain populations may only be present seasonally, especially mobile livestock keepers. Recession farmers can supplement their food resource base, income or increase the fertility of their fields by bartering cereals and fish for milk and meat products, charging levies for grazing on the stubble fields or ‘cultivating’ specific grasses appreciated by the livestock of nomadic herders, as is done in the ‘bourgoutières’ (plains where *Echinochloa stagnina* grows) of the Niger River Inner Delta in Mali.

There are many possible variations on this theme using different crops. For example, in drier areas sorghum or millet will replace maize, or cash crops such as cotton or sesame may be favoured. Different types of beans and vegetables such as okra (*Abelmoschus esculentus*) and other Malvaceae such as *Hibiscus sabdariffa* (roselle, ‘bissap’) and various Cucurbitaceae (squashes, melons, gourds, cucumber, pumpkins, luffas and watermelons), onions, tomatoes and spices (various types of chilli but also aniseed, cumin, garlic, etc.). Sweet potato can be a high added-value crop on sandy dunes in proximity to water bodies.

Box 11.2 Just add water: recession agriculture of Lake Faguibine in Mali

About 100 km west of Timbuktu lies ‘Lake Faguibine’, a triangular depression of about 50,000 ha (Hamerlynck et al. 2016). The rainy season consists of a few showers totalling about 100 mm between August and October, when the dunes neighbouring the ‘lake’ briefly turn green and are grazed mainly by camels. In December water appears in the lake’s south-eastern corner, some 175 km from the banks of the Niger River. By March the lake is flooded and Bozo fishers, who have brought their canoes on donkey cart, set up their gill nets. Up to 3 km away from the edge of the water, Eklan and Bella groups start hoeing and plant three seeds in each pocket: a seed of maize (to be harvested in June), a seed of sorghum (to be harvested in September) and a bean or some other crop (cotton, groundnuts, vegetables). As water infiltrates into diatomite soils and evaporates in the hot desert winds, farmers move down with the water’s edge and put the emerged land under cultivation. The only inputs are seeds and labour, keeping livestock out of the fields, harvesting, loading the produce on donkeys and taking it to the market or storage.

This is recession agriculture at its best. No hydraulic infrastructure, no machinery, no pumping (the lake is about 10 m below the flood level of the Niger River), no fertiliser and no pesticides. Organic farming in the Sahara and all done by the ‘poorest-of-the-poor’, the recently affranchised subservient castes! Admittedly, production per ha is low (only 1 or 2 tonnes) in comparison with the theoretical maximum expected in irrigation systems. Recession agriculture works and has done so for centuries, which is more than can be said for the nearby large-scale irrigation system of Lake Horo. That system has cost several thousand \$US per ha to build, and many millions to run until both the donors and the government gave up. Its traditional users have now gone back to recession agriculture, which functions very well at a fraction of that cost (Adamczewski et al. 2011). In the Sahel many intermediate forms of water control exist, from purely passive inundation to ‘modern’ irrigation (Barbier et al. 2011). The traditional and modern systems are complementary and successful small-scale irrigation (wheat, rice, vegetables, spices) using a pump, and a simple layout of small embankments is found in the higher floodplains along the canals supplying the Faguibine system.

In spite of its socioeconomic effectiveness, recession agriculture has hardly been researched (in Google Scholar it will yield a few hundred hits while irrigation yields millions) or promoted. It works as long as flooding regimes of rivers are maintained, restored or enhanced by managed flood releases from hydropower dams, even when subsidies are withdrawn (Comas et al. 2012).

Deltaic fish-based farming subsystem

Most of Africa's major river systems with a coastal outlet form deltas where sediments brought down from the continent are deposited. These are colonised by extensive and highly productive mangrove systems, especially where there are strong tides that create dynamic interchanges between fresh and marine waters. Key areas in west Africa include the 'Rivières du Sud' between the Sine Saloum estuary in Senegal and Sherbro Island in Sierra Leone (Cormier-Salem 1999), and the Niger and Cross River deltas in Nigeria. To the north of and in between these systems are more dynamic coasts that support the sandy coast fish-based farming subsystem. From central Africa to Angola, most of the coasts are highly dynamic and mangroves are confined to the main estuaries. The same is true for the (small) estuaries along the coasts of southern Mozambique. Substantial deltas with characteristic mangrove systems reappear at the mouths of the Save and Pungue Rivers, but the major ones along the east African seaboard are the Zambezi and the Rufiji (Richmond et al. 2002). The Ruvuma and Tana Rivers also have much smaller but important deltas. The mangroves in the estuaries of western Madagascar share the same characteristics (Duvail et al. 2017).

The fisheries in the deltaic subsystem target many species, but major, often export-oriented, income earners are the crustaceans, especially shrimp and crabs but also sharks for their fins. Traditionally, penaeid shrimp are caught using passive fish barriers using the tides, but inshore areas of deltas can also be intensively fished by trawlers (Munga et al. 2012), which can lead to conflict when they interfere with small-scale operations. The high bycatch-(especially of juvenile fish)-to-shrimp ratio of trawlers draws complaints, especially when discards wash up on shore. Finfish are important for the local food supply, especially the fatter clupeids, shads, mullets and tarpons that can be smoked and dried. Smaller fish and shrimps caught with mosquito nets, often by women, are also dried and used as seasoning. Depending on the surroundings of the specific river mouth, households can combine this type of fishery with coral reef or soft substrate fishery (or even lake or floodplain fishery), often on a seasonal basis or in a shorter lunar-based cycle in accordance with the migrations and activity patterns of the target species.

Figure 11.9 Harvesting of tidal rice in the Tana Delta, Kenya; tree crops include coconut, banana, mango and Nipa palm.

Source: Olivier Hamerlynck.

Again, the farming system with which the fisheries is associated will depend on the climatic zone and LGP, but tree crops such as coconut, banana, mango and other fruits and various palms (oil palm, nipa), cereals such as maize, and root crops such as cassava, feature prominently where conditions are favourable. In both west African and east African deltas, one very specific form of cultivation in this subsystem is tidal or mangrove rice cultivation, combining river floods and the tidal bore to passively irrigate fields cleared in the mangrove system (Figure 11.9). These lands are often targeted for industrial shrimp aquaculture.

Trends and drivers of change across the system

Fifty years after independence from colonial rule, the fish-based farming system in Africa is still struggling with the colonial and early post-colonial attitude of “local systems are inappropriate and either underperform or overexploit and they need to be replaced by ‘modern’ i.e. western European/American models”. Projects and programmes funded by multilateral and bilateral partners, national discourse and training programmes tend to push for radical change in resource use systems, emphasising private property, increases in scale and industrialisation of harvesting and processing. This approach tends to emphasise economic rent rather than social welfare (Béné et al. 2010a). In addition, choosing ‘modernity’ often means ignoring or externalising environmental and social costs, which harms biodiversity and thus undermines ecosystem service delivery and the well-being of vulnerable people. Indirect drivers of change (Nelson et al. 2006) such as demography, economic processes (e.g. globalisation), scientific-technological innovation, distribution pattern processes (as captured by the income inequality or GINI index) and cultural, social, political and institutional processes (belief systems, governance, policies, legal framework) have major impacts on the functioning of the fish-based farming system. It is important to recognise that different cultures may evolve along different development pathways (Harrison and Huntington 2000). Influencing these indirect drivers requires intervention at the political level, often on a regional or even global scale. The direct drivers of change include land use change (deforestation, expansion of cultivation into increasingly marginal areas, large-scale biofuel plantations); resource extraction patterns (mining, protected areas) and the increased use of external inputs (fertilisers, pesticides, irrigation water); development of energy sources such as hydropower and fossil fuels and their associated emissions of greenhouse gases; and the modification (genetic engineering) and movement of organisms (in particular invasive species associated with aquaculture). These are particularly strong impactors on the system. This chapter will focus on drivers specific or local to the fish-based farming system, which are summarised later in Table 11.3. Many of the drivers have strong interlinkages and can all push in the same direction. The subdivisions below are therefore somewhat artificial.

Demography

Sub-Saharan Africa’s population has been growing very rapidly but is in transition with fertility rates decreasing in general and, as a consequence, annual growth rates trending downwards towards 2 per cent, expected to be reached in sub-Saharan Africa between 2040 and 2050 (United Nations 2013). North Africa has already achieved this transition. Population tends to be high in comparison to the availability of social services and ecosystem productivity. With often about half of the population below 15 years of age, the strains on education and development of gainful employment opportunities will continue.

Figure 11.10 Migrating (often transnational) groups of fishers funded by city-based investors are increasingly competing with local, farm-adjacent, part-time fishing operations. The migrants often use destructive gear that damages the resource base, in this case a very large seine net that will rake the coral reef. These nets have been provided by well-meaning development projects and were originally intended for offshore pelagic fishing (Tanga, Tanzania).

Source: Olivier Hamerlynck.

Massive un- and underemployment have associated risks of political instability and declining well-being. Longer lifespans mean increasing dependence ratios and additional stresses on the poorly funded health systems. New chronic diseases such as diabetes, hypertension and cancer require adaptation of the service delivery systems, so far primarily geared towards infectious and parasite-related ailments.

Associated with these demographic trends is rapid urbanisation, including in the coastal parts (Parnell and Walawege 2011) of the fish-based farming system, around the Great Lakes, and around floodplains with an associated high and ever-increasing demand for affordable fish protein. Poverty levels can be expected to remain high, and hunger can occur, especially when the water-related ecosystem services are hampered by inadequate floods.

Natural resources and climate

The fish-based farming system is highly dependent on water quantity, quality and dynamics, and draws on both the characterising water sources and local rainfall. The variability

in weather, climate and water resources resulted in the development of broad and flexible livelihood portfolios, especially in the dynamic floodplain and deltaic systems where target species (both fish and invertebrates) are more opportunistic.⁴ While the flexibility makes these farming systems more resilient, they are still susceptible – very few human societies can forego a few successive dry years or even a single production season. This was evident during the prolonged droughts in the Sahel (1970s to 1980s) and currently in the Horn of Africa.

For major parts of the system, productivity is dependent on the flood pulse linked to the pronounced seasonal rainfall patterns. In the flood-dependent systems, almost all resources react in concert as they are all dependent on the same drivers, i.e. there are bundles of water-related ecosystem services. Even the seemingly more static lake systems are dependent on flood pulses, mainly through their effect on the nursery areas. In an increasing number of basins, the beneficial effects of the flood pulse are in jeopardy as deforestation and land degradation create sharper and shorter floods. Trends are towards declining recession agriculture, pasture production and fish reproduction. Also, river regulation by storage dams decreases the flooded surface area and system productivity (Box 11.3). Large-scale irrigation systems tend to ‘replace’ the system and exclude or marginalise its traditional beneficiaries.

The easy entrance into fishery and its attractiveness to young males means that the number of fishers can be expected to continue to grow and contribute to overfishing, especially through externally financed migratory operations. Fisheries conducted near the homestead have incentives to use sustainable techniques and levels of exploitation, often formalised through traditional governance systems. When harvesting away from home such considerations become irrelevant from the fisher’s perspective. Migratory (and destructive) fisheries (Figure 11.10) are typical for west Africa (Chauveau and Jul-Larsen 2000), and are increasing along the east African coast (Crona and Rosendo 2011), the lakes (Geheb and Crean 2003) and even in floodplains of the Zambezi and the Rufiji.

Overfishing is apparent when increased effort no longer results in increased total catches or when the average size of the fish landed is decreasing (Welcomme et al. 2010). In Lake Victoria (Kolding et al. 2008) eutrophication from urbanisation, deforestation and expansion of agriculture has resulted in higher lake productivity but has also favoured alien, invasive water hyacinth (*Eichhornia crassipes*) and an increased risk of anoxia.

Global climate change models are performing well, but the models at the scale relevant for the fish-based farming system have high uncertainty levels (Müller et al. 2011). Climate models for the Sahel predict anything between a 30 per cent increase to a 30 per cent decrease in rainfall (Shanahan et al. 2009). Prolonged droughts and reductions in flooded surface areas would be detrimental for floodplain and deltaic subsystems and negatively affect lake and coastal systems. It would therefore seem wise to prepare for a (few) worst case scenario(s). More extreme (rainfall) events and associated short and sharp flood peaks hamper fish reproduction and may wash away crops.

For coral reef systems additional declines in the resource base are expected through climate change-related ocean acidification (Hoegh-Guldberg et al. 2007), rapid sea level rise and increased storm damage. These vulnerabilities, based on an index that combines sensitivity and adaptive capacity, most strongly affect sheltered, high water temperature coasts such as Kenya, Tanzania and north-west Madagascar where communities are already stuck in a poverty trap (Cinner et al. 2012).

Box 11.3 The restoration of the Senegal River Delta in Mauritania: a success story

After the Sahel drought of the 1970s and 1980s two dams were built on the Senegal River, a storage and hydropower dam upstream at Manantali in Mali and a salt-wedge dam close to the river mouth at Diama. The multifunctional floodplains in between, traditionally consecutively used for fisheries (flood season), recession agriculture and livestock grazing (dry season), were to be converted to several hundred thousand hectares of irrigated agriculture. When the dams were completed (in 1990) the productive delta, which had already lost biodiversity values and ecosystem services during the drought, was excluded from flooding and turned into a saline desert. Hundreds of hectares of mangrove died, the rich *Echinochloa* pastures shrivelled up, thousands of hectares of *Sporobolus* used for traditional mat weaving disappeared and the rich shrimp and finfish fisheries collapsed.

Between 1993 and 1997, sluice gates were built in the Diama Reservoir embankment allowing re-flooding of the major deltaic floodplains and subsequently flush the estuarine part. Designed through a participatory process emphasising local knowledge, the co-management arrangement mimicked the original optimal flooding (Hamerlynck and Duvail 2003).

Under the managed flood releases the grassland ecosystems bounced back quickly, and currently, after 20 years of re-flooding, the mangrove and floodplain *Acacia* forests have reached maturity. The communities of fishers, livestock keepers and farmers revived. About 60 fishery households produce 150 tonnes of fish and 1 tonne of shrimp annually, earning over US\$100,000 (about US\$10 a day during the five-month season). After flood recession, thousands of cows come to graze. The dunes and floodplain edges where groundwater recharge has taken place produce vegetables, mainly onions and beets. The biodiversity has also bounced back with several hundred thousand migratory and breeding waterbirds present during the flooding season. The area has now been designated as a biosphere reserve.

In contrast, after 25 years of repeat funding of the irrigation schemes in the Senegal Valley, even the development bankers admit that, out of the hundreds of thousands of hectares of irrigation envisaged, the few tens of thousands of hectares that have actually worked (for a while) are highly unlikely to ever be economically viable (Dickmann et al. 2009).

Energy

The fishing operations in the system have a low level of mechanisation and consumption of fossil fuels, except for the largely motorised canoe-based west African fisheries, but much of the fish processing is still wood energy intensive and impacts on vegetation can be substantial (Abbot and Homewood 1999; Feka and Manzano 2008) in spite of improvements through the use of wood-saving kilns ('chorkor'). These are still not used everywhere and are also not easy to install in areas that flood. Appropriate technology breakthroughs could lead to major productivity gains by reducing the high post-harvest losses and save energy at the same time (e.g. mobile processing kits and solar drying).

Human capital/knowledge sharing/gender

The mobility linked to the strongly seasonal characteristics in large parts of the system impacts negatively on school attendance. Even in more sedentary settings, the emphasis of national and donor-driven programmes seems to have been on larger coverage of the school-going population rather than quality. As a result teachers often come from areas outside of the system and rarely address understanding of the local environment.

Vessel-based fisheries are almost exclusively male, but women (and children) do fish, in particular on foot using mosquito nets and traditional baskets or gathering by hand on reef flats, targeting species (fish, crustaceans, molluscs) or life stages that will not affect the commercial fishery. The small amounts taken are important in the food spectrum especially for the most vulnerable women-led households. The health benefits of eating even tiny amounts of fish for developing children cannot be over-emphasised. Still, the use of mosquito netting (Figure 11.11) typically triggers repressive regulation associated with government-imposed mesh-size restrictions (Abbott and Campbell 2009) not based on an analysis of its impacts. A few hundred women, who twice a month (during spring tides) pull a 3 m wide mosquito net over 50 m in a 50,000 ha mangrove system to catch a few kilograms each of Sergestid shrimp to sun dry and use as a food seasoning, are unlikely to endanger the resource. The regulatory bodies tend to ignore traditional and local knowledge and often operate on assumptions rather than observation. Co-construction of knowledge based on participatory monitoring and research could be highly beneficial (Duvail et al. 2014). In many areas women play a key role in fish processing.

Figure 11.11 Fishing a seasonal pond in proximity to the floodplain farm in Rufiji, Tanzania using traditional baskets for catfish and a mosquito net for small freshwater shrimp. In theory this is illegal, but as the pond will dry out within a month the fish will die anyway.

Source: Jean-Luc Paul.

In east Africa especially there is scope for the empowerment and capacity building of women. Culturally, the odds are stacked against women, for example household workloads, getting hold of cash, land inheritance or even simply holding on to the hut and the basic household tools in case their husband dies (these can be taken back by his family). Gender issues also feature prominently in the alternative livelihoods that are proposed by the conservation-minded non-governmental organisations (NGOs) such as seaweed farming. Promoted as a success story (the cosmetics industry buys these products very cheaply), the activity entails unacceptable workloads, very low pay and a high disease burden in the women (Fröcklin et al. 2012). A large proportion of the women in the fish-based farming system are stuck in a poverty trap, and it will require some seriously innovative thinking to help them to get out through sustainable livelihood development and breaking down the social, economic, cultural and political barriers that are keeping them trapped.

Science and technology

The availability, effectiveness and simplicity of nylon nets have been a major driver in the expansion of fisheries in Africa, not only for full-time fishers but also in former exclusively farming households. Increasingly, cheap but illegal monofilament nets are entering the market, replacing traditional gear made from natural biodegradable fibre. Monofilament gear ‘continue to fish’ even when they are lost or discarded – so-called ghost fishing (Matsuoka et al. 2005).

African coastal income-generating activities catering for global markets can, in general, not compete with the Southeast Asian operators. New techniques with good potential such as fish-aggregating devices, which can bring pelagic species such as tuna within reach of artisanal fishers operating from small vessels, have been insufficiently tested, supported over too short periods or introduced in inappropriate locations. The use of artificial reefs and enrichment techniques using juveniles of target species are still in their infancy. Development projects tend to concentrate on changing a single aspect of the activity and focus on productivity gains by introducing ‘better’ things, i.e. bigger boats, stronger engines, larger nets or adding ‘more of everything’, often in the places where the fishery is already saturated. Sustainable development of commercial fisheries in this system requires appropriate, integrated management of the ecology, market and trade issues to facilitate adoption and success.

Other enhancement technologies such as fingerponds (Kipkemboi et al. 2007) have not been tested appropriately, neither have the associated market and trade issues been looked into (see ‘Markets and trade’).

The programme to eradicate the tsetse fly across sub-Saharan Africa (Van den Bossche and Delespaulx 2011) opens up parts of the system to livestock with major implications for the household livelihood spectrum. Tsetse-ridden African savannahs were naturally protected and often turned into national parks or reserves (Beale et al. 2013). The eradication of river blindness similarly led to biodiversity loss (Thiollay 2006). Massive changes in land use, such as proposed by the World Bank (2009), to turn savannahs into cereal-growing areas will not only affect biodiversity but also water availability in the adjacent fish-based farming subsystems.

Science and technology that builds on what already exists locally, looking for incremental improvements rather than wholesale change, should be promoted.

Markets and trade

Land has become a major market commodity (Margulis et al. 2013). In its euphemistically titled report (Hall 2011) *Rising Global Interest in Farmland: Can It Yield Sustainable and Equitable Benefits?* the World Bank points out that of the 45 million ha under negotiation in 2009 by, essentially, foreign investors, 70 per cent were in Africa (Deininger and Byerlee 2011). Much of this land grab intended for biofuel rather than for food production, is in fact also, or even mainly, a water grab (Mehta et al. 2012; Woodhouse 2012). It will have major impacts on the fish-based farming subsystems, even when the land use conversions are on system-adjacent lands (Duvail et al. 2012). Sovereign wealth and hedge funds are speculating on commodities and can create food scarcities against which the vulnerable, who face challenging survival decisions almost every day of their lives, have no defence.

Large water bodies in the tropics and subtropics, especially coral reef coasts but also lakes, are attractive to the affluent in temperate areas. In Kenya, tourism accounts for about US\$100 million annually, more than the export of coffee. In Zanzibar tourism represents about 20 per cent of GDP, about half the income from cloves *Syzygium aromaticum*. Tourism can, in principle, be an effective development lever as it can create non-extractive livelihoods. But it can also lead to exclusion of already marginalised fishers from badly designed marine protected areas (Wamukota et al. 2012). Locals rarely benefit from tourism development because conversion from fishing/farming requires a too large capacity jump. Tourism is sensitive to even 'small' and localised incidents such as a single bomb in a bar, a disease outbreak (a few cases of cholera) and electoral violence, which can have multi-year impacts. The low-level jobs that the locals have access to are usually the first to suffer when a freak incident occurs. This is especially true for tourism based on coral reefs in Africa as there is ample competition from Caribbean, Southeast Asian and Pacific coastal and island states.

The spread of mobile phones and cheap sturdy motorbikes is improving marketing in many areas. A major constraint remains with fish processing and conservation techniques.

Policies and institutions

The dominant narrative about fisheries in the fish-based farming system is that they are overexploited and that the massive use of illegal and destructive gear is responsible for this. Marine fisheries on continental shelves are indeed almost all overfished but mainly by industrial operations (Pauly et al. 2002). The same does not necessarily hold for the small-scale fisheries that concern us here. Lack of understanding of the diverse and flexible resource use strategies of the fisher-farmer as well as of the functioning of the complex ecosystems they rely upon has hampered the development of useful and effective management advice.

Understanding of the system's functional requirements and its wide-ranging benefits is scant in both government and development agencies, and thus some pessimism about its future is justified. Emphasis has been on taking more out of the system through industrialisation and upscaling, including for export, but many of these schemes have failed. Another trend is towards externally financed larger-scale operations at greater distances from the farm. Less attention has been directed to maintaining and enhancing system productivity through ecosystem management interventions and facilitating the small-scale fisher-farmer's operations through co-management. The absence of an enabling

environment and heavy local taxation result in farmer emphasis on self-sufficiency rather than marketing.

In certain areas, fishing operations are still regulated by traditional local institutions, but the trends are towards largely ineffective state-based regulation (often not flexible enough to adapt to local conditions), or free-for-all situations leading to overexploitation. Traditional governance systems have either been ignored or dismantled by colonial and post-colonial governments seeking to replace them with ‘modern’ institutions. Small-scale fisheries operations, in spite of its unselective nature and its violation of policy and legislation on minimal size, seem to be appropriate to maintaining the structure and functioning of exploited ecosystems (Kolding and van Zwieten 2014).

Comprehensive government control is technically impossible at reasonable cost and also hard to implement because it is not adapted to context. Thus nationwide mesh-size regulations may make sense for the comparatively simple three-species Lake Victoria fisheries, but they are meaningless and even counterproductive for other ecosystems where fishers adapt their gear to seasonal and inter-annual variability (e.g. flood extent), to the behaviour of individual species, and to opportunities and labour demands of other livelihood activities such as farming (Hamerlynck et al. 2011). Many fisheries are thought to be open access or common property resources whose traditional access regulations have been eroded and that therefore could easily lend themselves to ‘tragedy of the commons’ (Hardin 1968) situations. Some parts of some subsystems are definitely overfished, but there are also many examples of traditional and modern mechanisms for collective action (Ostrom 1990) that regulate effectively. Some of the most spectacular of these are the collective fisheries in seasonal wetlands in west Africa (De la Croix et al. 2014), where rituals are required before the ‘Master of the Waters’ officially opens the season and thousands of people can enter the water simultaneously (Figure 11.12). These collective fisheries also involve complex catch redistribution mechanisms (Jacob 2003).

Figure 11.12 Collective fisheries in the floodplain of the Niger River in Guinea.

Source: Kevin de la Croix.

The sectoral thinking and planning by development institutions forces an artificial distinction between the fisheries and the farming parts of the system, although both are strongly interlinked. A similar concern occurs where integration is required across other sectors such as water, natural resources, wildlife, tourism and health. With the trend towards decentralisation, integration should in principle become easier, facilitated through local level, inter-sectoral dialogue and participatory planning with the resource users. When conducted by people who are in touch with the household realities, some of the large-scale quagmires we have been led into by the centralised government outlay and the export-oriented donor support may be avoidable. Still, at the local government level, there remain issues with capacity and the means to mainstream bottom-up processes.

Fisheries management models were essentially developed for single species fisheries in the North Atlantic and are inappropriate for the overwhelming complexity and diversity, both biologically and socioeconomically, of the multi-species, multi-gear, multi-user fisheries of Africa's coastal and inland waters. Instead of trying to force these imported models onto the system, it would seem more appropriate to study the system's rapid adoption of 'things that work', and to gradually improve and mainstream on the basis of their socioeconomic and ecological impacts. The relative success of the west African canoe fisheries (Chauveau and Jul-Larsen 2000) and the Lake Victoria fisheries (Kolding et al. 2008) are cases in point. These have not followed externally planned trajectories but have built themselves up on the basis of a wide array of local assets, whether technical, social or organisational.

Table 11.3 Summary of drivers, trends and implications for the fish-based farming system

<i>Driver of farming system evolution</i>	<i>Trends and implications</i>
Demography	High population growth rates to continue for several decades with further reduction in farm size and catch per fisher with expansion of destructive migratory fisheries and increasing demand from urban centres
Natural resources and climate	Increased variability, extreme events and uncertainty leading to declining system extent and productivity
Energy	Construction of large numbers of hydropower dams affecting system extent and productivity. Increased use of wood fuel leading to deforestation and land degradation
Human capital/knowledge sharing/gender	Education levels remain low and further marginalisation of poorest fisher-farmers and women, e.g. through mesh-size regulations based on beliefs, not on sustainability criteria can be expected. There is a lack of exchange between traditional and technical knowledge
Technology and science	Expansion of unsustainable agriculture into marginal areas and floodplains with exclusion of traditional users and decline in ecosystem service delivery
Markets and trade	Globalisation, land and water grabbing, increased power of speculative capital, rising inequity leading to increased vulnerability and political volatility
Policies and institutions	Lack of understanding of the ecological bases and sociocultural contexts of the production systems leading to ineffective interventions

Macroeconomic advances do not necessarily ‘trickle down’ or lead to greater equity. Vulnerable groups (e.g. women-led households) need specific attention, often through collective action within common property regimes. In the past, cooperatives (neither required nor understood) were created top-down and failed. Unfortunately, interesting initiatives that were initially successful, such as the reduction of dynamite fishing in the Tanga area in Tanzania, proved to be very donor-dependent and collapsed when external support and follow-up were withdrawn (Samoily and Kanyange 2008). More recent and better thought-out attempts to reverse the negative trends, for example in the management of coral reefs, have involved organising coastal communities to become self-regulating.

System and subsystem performance

Sustainably harvesting the fish-based farming system to benefit human well-being, while maintaining the system’s structural and functional integrity (Weeratunge et al. 2013) should in principle be possible as the system is highly productive and resilient. Unfortunately, sharing the benefits equitably so that everybody, including women and other vulnerable groups, can move together towards a better future is hampered by many political, economic, social and environmental constraints, locally, regionally and globally (Béné and Friend 2011).

In the fish-based farming system, there has been technical progress but not improved quality of life for the greater number. Fisher-farmers are not paid enough for what they produce partly because they have little or no negotiating power with those who transport and market their perishable produce. They are overburdened by nuisance taxes and face many administrative hurdles. Elders in the villages doubt whether they have seen improvement since the 1960s, with the exception perhaps of a lowered disease burden (treated mosquito nets), sturdy bicycles (capable of transporting over 100 kg over several tens of kilometres along bush paths) and, increasingly, motor cycles, cheap second hand clothing and the ubiquitous flip-flop sandals (which are conveniently recycled as floaters for gill nets). Still, mobile phones are now used to seek traders to buy the catch even while still in the canoe and also to enquire about market prices and weather patterns for sowing.

The sustainability and equity issues faced in the fish-based farming system do not only come from the ‘big bad world far away’. The burgeoning African cities also draw away ecosystem services that the fisher-farmers directly depend on; the politically vocal, urban classes are more effective in pressurising decision makers for more water (Komakech et al. 2012), more electricity, more cheap food, more cheap charcoal, more cheap furniture and more protected areas for leisure. The rural populations rarely receive adequate compensation for what is taken away from them, for example the downstream impacts of hydro-power dams on floodplain, deltaic and coastal fisheries.

Assessing system performance requires indicators that focus on human well-being and ecosystem service delivery (Pinto et al. 2014; Ringold et al. 2013) across the spectrum of activities in the fish-based farming system. These will of necessity be context specific or ‘place based’ as there are many sociocultural differences, historical pathways and adaptations to the specific ecosystem where activities emerged. Jointly developing and monitoring these indicators with the stakeholders will help the technical staff from government or management authorities to understand the real issues affecting system performance.

The sandy coast fisheries have performed comparatively well for decades, but over-exploitation has become an issue and nursery areas are affected by land use change and

infrastructure development. Human well-being indicators such as income, health and education remain low, often lower than the country's averages, while the demography is very dynamic. Behind the strip of flamboyant beach hotels along the shores of the Indian Ocean there is a more prosaic reality. In the fisher-farmer villages, in spite of adequate rainfall and a favourable LGP, agriculture is confronted with shallow soils on fossil coral rag or leached sandy soils. Various tree crops can be grown, including coconuts, but many plantations are senescent. Mango, banana, cashew, jackfruit and citrus trees can be profitable, but trade is affected by overproduction peaks and inadequate capacity to transport produce and transform it. Rice is grown in seasonally flooded depressions, and other cereals such as maize, sorghum and millet are grown on higher ground. Around the homestead or in fields cleared in secondary forest, crops such as cassava, legumes, vegetables, fruits such as pineapple, and spices are grown. In proximity to tourist resorts these find ready markets. However, beach tourism and rapid urbanisation push land prices beyond what locals can afford, and access to fish landing points can become difficult as beachfront properties expand. Similarly, access to fresh water is increasingly an issue as demand increases and shallow aquifers are overexploited and become saline (Bakari et al. 2012). This trend is likely to be compounded by sea level rise. Cement quarries that strip-mine the fossil coral are another competitive land use. For the fisher-farmers, the remittances from family members engaged in various types of off-farm activity, including from migrants to affluent countries and urban centres, are a substantial source of income, allowing access to credit and equipment (e.g. rural electrification, drinking water supply).

Coral reef fisheries represent an estimated 10 per cent of the world's fish catches (Smith 1978) from about 0.1 per cent of sea bottom area (Spalding et al. 2001), and they are therefore productive but also highly exploited and vulnerable. De Groot et al. (2012) estimated the value of coral reefs is up to US\$350,000 per hectare per year, mainly linked to their tourism potential. Their other ecosystem services, including protection against erosion and nursery functions, are mostly non-tradable public benefits, but replacement value is often only understood after the reefs have been destroyed.

Coral-reef fish-based farming subsystems are typically caught in a socioecological trap, even in places where reefs are still productive (Steneck 2009). In areas with *low* socioeconomic development and intact traditional governance, fishers simply do not earn enough to acquire the tools for overexploitation. The reefs could sustain a higher fishing effort, but there are no marketing opportunities. Life is comparatively good but operates at subsistence level. Monetary poverty makes improved education unattainable. In areas of *intermediate* development, where traditional institutions have collapsed and 'modern' ones are ineffective, overfishing and destructive techniques are rife. Here the human well-being indicators are in the red, and it is hard to see how to move them towards the green as the resource base itself is compromised. At the other end of the spectrum, in areas with *high* socioeconomic development, reefs are again in better condition as institutions are stronger and there are incentives for regulation, e.g. by the effective management of Marine Protected Areas (MPAs) that bring in tourist revenue. More non-fishing livelihoods are available and there is access to motorised vessels allowing fishing further off-shore (Cinner et al. 2009), thus reducing the pressure on the reefs. The impact of MPAs is highly variable across different governance and management regimes, but a minimum area of 5 km² and high compliance with the restrictions are the key success factors (McClanahan et al. 2009).

There is a strong correlation between excessive fishing pressure and reef degradation, with the most fundamental and deleterious shift being a change from a dominance of hard

coral to algae or sea urchins. Little is known about how these phase shifts occur, but there is now some pragmatic understanding of reef function and its fisheries-related tipping points (McClanahan et al. 2011). To avoid overgrowth by algae it is essential to keep fishable biomass above 500 kg/ha, ideally above 1000 kg and certainly above 300 kg. Below that threshold fish-dependent livelihoods are compromised.

With a total production of 1 million tonnes per year, the Lake Victoria fisheries are now the largest freshwater lake fisheries in the world, operating in the world's second biggest, but comparatively shallow, freshwater lake (68,000 km² but maximum depth less than 100 m). In Africa's lakes, the number of fishers stabilises at production levels of about 3 tonnes per fisher per year (Kolding and van Zwieten 2011). When catches consistently fall below that level, most fishers will shift to other activities either seasonally or permanently. Post-harvest losses of fish, partially through insect infestation, are substantial (Akande and Diei-Ouadi 2010), but pesticide use to combat this may pose health risks for those who apply it and those who consume the fish.

Strategic priorities for the system

Table 11.4 summarises the strategic priorities for the fish-based farming system. As interventions in the farming part of the system are treated in other chapters, the emphasis here is on the fisheries-oriented aspects, in particular maintaining structural and functional integrity, especially by maintaining flood pulse characteristics, including through managed flood releases from dams. Some key issues are discussed below.

There is a need to identify the science, technology, knowledge and human capacity needs for the system. Science is a method to acquire reliable knowledge, ideally used to solve problems identified by the people who are confronted with them. These people should conduct or at least actively participate in the research, in collaboration with people

Table 11.4 Strategic priorities for the fish-based farming system

<i>Drivers</i>	<i>Intervention</i>	<i>Implementers</i>
Natural resources and climate	Maintain and enhance adequate flood pulses and ecosystem integrity especially for nursery areas. Plan for worst case scenarios	Government, private sector, NGOs, development partners
Energy	Design and manage hydro-electric dams for environmental flows to maintain downstream socioecosystems	Dam designers and managers
Science and technology	Co-construct context-specific knowledge; pilot and mainstream incremental technological improvements especially in fish processing	Scientific and engineering community, NGOs, local government with holistic rural extension workers
Markets and trade	Lift nuisance taxes and address marketing constraints such as transport and processing. Ensure land and water security to resource user communities	Government
Policies and institutions	Changeover from GDP-oriented thinking to context-specific, ecosystem-based co-management arrangements targeting human well-being	Government, NGOs, development partners

familiar with the scientific method, in order to explore and test potential solutions. This co-constructed knowledge, drawing on both local experience and the scientific method, can then be made available in the appropriate format such as feedback sessions with role play (Duvail et al. 2014) to those who need that knowledge to make the changes required, e.g. the local leadership.

The need for some serious advances in fish processing technology under tropical conditions has already been emphasised. The reduction of post-harvest losses probably represents one of the biggest potential gains in productivity in small-scale fisheries. Post-harvest losses are immense, and current processing techniques either consume lots of wood or have health issues (insecticide sprays). Simple solar ovens do seem to work, especially in the drier areas, and reduce wood consumption in places where it is in short supply. Research into appropriate technology for each of the subsystems, in close collaboration with the operators, should be given a high priority. In choosing technologies, consumer preferences need to be taken into account and prices need to be kept low to keep protein affordable for the vulnerable. Still, in theory, the engineering required should be less complex than sending a life-seeking probe to Mars or creating a Higgs boson. Possibly a question of priorities, therefore.

Aquaculture offers opportunities to diversify and intensify. Africa only contributes about 2 per cent of global aquaculture production, but the practice is rapidly expanding (FAO 2012). Care should be taken to avoid the introduction of inappropriate species and to promote production of fish that are low rather than high in the food chain (e.g. tilapia); control the conversion of edible fish into fishmeal; and, in particular, make sure that aquaculture does not subtract from the natural systems by encroaching on the productive margins of existing water bodies. Small-scale testing, incremental technological improvements and household level roll-out may be the more sustainable approach and beneficial to many rather than the few (Allison 2011). Rather than search for sophistication, culture of the ubiquitous oil-rich and nutritious catfish *Clarias gariepinus*, which can feed on just about everything, survives in almost any habitat and is the perfect fish to be smoked, offers opportunities in simple village ponds seeded from the wild.

Planning and management also need to address natural resource issues in the fish-based system. Eutrophication, as observed in Lake Victoria, is a comparatively new threat likely to become important elsewhere. Irrigation systems should be designed to add to and not subtract from the natural system, to maintain input-effective recession agriculture and other flood-based biodiversity, ecosystems and livelihoods. Climate change uncertainties should engender planning for wide error margins for infrastructure in or around floodplains.

Co-management, based as much as possible on traditional governance systems, has a better chance of being effective in banning proven destructive techniques and safeguarding nursery areas and reproductive seasons. It is vital that the technical support and regulatory roles of government be strictly separated to maintain mutual trust. Repressive interventions should be based on joint analysis of the need and agreement on the approach. Mesh-size regulations in particular should be much more flexible and adapted to local conditions. Enforcing national mesh-size regulations across different ecosystems is counterproductive, and ideally these should be locally adapted and accepted through community bylaws with the government stepping in only at the request of the local co-management institution.

Much can be learned from projects initiated by NGOs, but interventions should preferably be embedded in local government and operate over medium-scale timeframes and not act as temporary substitutes for the state. Support through holistic (non-sectoral) and non-dogmatic rural extension workers with a thorough understanding of the local context and favouring incremental improvements in technology should be prioritised. Ideally this will be guided by a set of principles for identifying and deliberating options for

governance reform through inclusive multi-stakeholder dialogue, evidence-based analysis, support for livelihood security and human rights, and addressing cross-sectoral and cross-scale interactions (Ratner and Allison 2012).

Africa requires more energy and more food, and the preferred options are now hydropower and (large-scale) irrigation. Both of these, if implemented without taking account of what is required to keep the fish-based farming system and its multiple social and ecological benefits intact, constitute a major challenge that needs to be addressed.

Hydropower is not a problem per se, but the way it will impact on the fish-based farming system depends on the choices that are made. Most of the optimal dam sites in Africa have already been equipped but unfortunately often without the design or operations to allow or implement adequate managed flood releases (Acreman et al. 2000) to maintain downstream ecosystems, in particular floodplains. Notable exceptions are the Senegal Valley, the Kafue flats on the Zambezi and the Waza-Logone in northern Cameroon. On a much smaller scale such releases have been used to rehabilitate a dam-impacted delta (Duvail and Hamerlynck 2003). New dams should have systems in place that ensure that they can and will produce managed flood releases.

After the World Commission on Dams (2000) report there was a slow-down in the funding for large dams, and the recommendations for environmental and social impact prevention and mitigation were quite stringent. This constraint has now largely been lifted with the advent of new donors and the private sector setting its own standards. The series of Gibe dams on the Omo River in Ethiopia threaten not only the fisheries, livestock keeping and deltaic farming around Lake Turkana but also the existence of the lake itself (Avery 2013). The Niger floodplains, vital for millions of people, are also threatened (Zwarts et al. 2005), and many other dams are being planned or are under construction on Africa's major river systems. Impacts will be tremendous unless environmental flows for multiple objectives are implemented (Acreman et al. 2014).

Where fresh water is available, including through improved harvesting techniques, intensification can be achieved through small-scale irrigation using small pumps. There has been uncontrolled development of furrow irrigation in many floodplains, affecting downstream users and blocking livestock and wildlife migration with increased risk for both farmer-pastoralist and farmer-wildlife conflict. Diversification, especially to high added-value crops (e.g. spices, trees), remains a reasonable option to improve livelihoods (Table 11.5).

Table 11.5 Relative importance of household livelihood improvement strategies

<i>Poverty escape strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total ag pop	—	48	52	100
Intensification	1	2	3	2.5
Diversification	3	3	3	3
Increased farm size	0	0	1	0.5
Off-farm employment	4	3	3	3
Exit from agriculture	2	2	0	1

Sources: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

Logically irrigation should supplement the fish-based farming system, not subtract from it. These schemes should, therefore, preferably be sited outside of the naturally flooding areas. Areas that are currently embanked but do not have performing irrigation schemes could be restored by changing dam management regimes or reopening embankments to allow natural flooding and recession agriculture. Because of multiple ecosystem services that natural or restored floodplains provide (Maltby and Acreman 2011), the net economic value of traditional multi-use floodplain management systems usually exceeds what irrigation schemes can provide. The economic calculations that supposedly show profitability of irrigation are often derived from high intensity situations with conditions that are unlikely to ever exist in real-life situations.

System conclusions

Small-scale fisheries are a key component of livelihood activities for a substantial proportion of the rural populations of Africa and are practised part time with a variety of gear by large numbers of men, women and children. These people also engage in farming, livestock keeping, forestry, hunting and gathering. The fisheries provide much-needed cash and protein to the 'farming' households and also support a significant number of land-based jobs in processing, transporting and marketing the produce, often over long distances. The comparatively cheap and, in comparison to bush-meat, sustainable protein that these fisheries produce is essential to the well-being of the majority of the vulnerable people of Africa and near impossible to replace by any other source.

There is nascent awareness in governments and development partners that investment in environmental infrastructure is required to maintain and enhance ecosystem service delivery and improve both biological and societal resilience. A holistic approach can become a much needed counterweight to two main threats to the system: hydropower storage dams that do not consider downstream socioecological systems and large-scale conversion of floodplains for irrigation. Such approaches are being tested at the appropriate transnational scale, for example by the West African Fisheries Commission that works in close collaboration with the Regional Partnership for Marine and Coastal Conservation in West Africa (PRCM) (Box 11.4). This programme, funded by a consortium of donor agencies and implemented by an array of international and local NGOs and CBOs in collaboration with other partners, includes a range of interventions at the conservation/sustainable use interface from which useful lessons can be extracted and mainstreamed.

A shift away from sectoral to ecosystem thinking is essential, to analyse the basis on which these production systems depend, especially adequate flood pulses, and to implement measures that can bring the systems back to sustainable production and ecosystem service levels with due consideration of the human well-being aspects. Empowerment of communities for increased control over their resources, including the establishment of co-management arrangements, will be required in many settings. Many of these interventions, including the development of household-based aquaculture, could benefit from the return of the rural extension worker. However, these need to be trained from a multiple livelihood perspective, with a strong ecosystem thinking capacity and skills in good governance and local institution building.

Box 11.4 A laudable attempt at regional integration and bottom-up planning in West Africa

Under the auspices of the intergovernmental Sub-regional Fisheries Commission, an innovative partnership has been developed in a series of west African coastal countries (Cape Verde, the Gambia, Guinea, Guinea-Bissau, Mauritania, Senegal and Sierra Leone), covering both sandy coast and deltaic fisheries. This Regional Partnership for Marine and Coastal Conservation in west Africa (www.prcmarine.org/en) comprises environmental NGOs, foundations and bilateral aid agencies working together using a holistic and multi-level approach to improve environmental governance, conservation and sustainable management of the shared regional fish stocks, fauna and flora. Interventions range from support for the establishment of Indigenous and Community Conserved Territories and Areas (www.iccaconsortium.org) by fisher-farmer communities, to traditional mechanisms for the control of effort (species taboos, closed areas and seasons). Their key objective is improving human well-being through conservation (not primarily targeting conservation outcomes), through the facilitation of a network of managers of marine protected areas, public forums, support for research proposals vetted by a scientific and technical council, policy-influencing, capacity building, stakeholder forums and advocacy including to lobby Members of Parliament in the different countries. This could be a model for other subsystems and transnational areas (e.g. Lake Victoria fisheries, the western Indian Ocean reef, deltaic and mangrove systems).

Notes

- 1 Defined as the freedom of choice and action to achieve basic material needs, health, security and good social relations (Scholes et al. 2005).
- 2 Artisanal fisheries (a term used interchangeably with small-scale or traditional fisheries, even though the scale can actually be quite large and that they have often evolved quite far from what would be strictly traditional, e.g. the use of nylon instead of natural fibre) refers to various low-technology, low-capital, fishing practices undertaken by individual households (though sometimes organised into cooperatives or associations).
- 3 In many societies cars are a status symbol, and the Mercedes Benz is a particularly powerful one across Africa, leading to terms like the Mama Benz for the comparatively rich, fish-trading women of the Gulf of Guinea and Wabenzi (literally ‘the people of the benz’) in the Swahili-influenced cultures in east and central Africa.
- 4 Schematically, living beings can be split into long-lived slow reproducing species that are adapted to stable and predictable environments, and short-lived fast reproducing species (i.e. opportunists) typical of dynamic and highly variable environments. Such species will produce very high numbers of young, most of whom will perish even in the absence of harvesting. Extracting a large proportion of such a population before it reproduces, e.g. by fishing out juveniles, will therefore not necessarily affect the capacity of the next generation to maintain the species.

References

- Abbot, J.I.O. and Homewood, K. (1999) ‘A history of change: causes of miombo woodland decline in a protected area in Malawi’, *Journal of Applied Ecology*, vol. 36, pp. 422–433.
- Abbott, J.G. and Campbell, L.M. (2009) ‘Environmental histories and emerging fisheries management of the Upper Zambezi River Floodplain’, *Conservation and Society*, vol. 7, pp. 83–99.

- Acreman, M.C., Farquharson, F.A.K., McCartney, M.P., Sullivan, C., Campbell, K., Hodgson, N., Morton, J., Smith, D., Birley, M., Lazenby, J., Wingfield, R. and Barbier, E.B. (2000) *Managed Flood Releases from Reservoirs: Issues and Guidance*. Report to DFID and the World Commission on Dams, Centre for Ecology and Hydrology, Wallingford.
- Acreman, M.C., Overton, I.C., King, J., Wood, P.J., Cowx, I.G., Dunbar, M.J., Kendy, E. and Young, W.J. (2014) 'The changing role of ecohydrological science in guiding environmental flows', *Hydrological Sciences Journal*, vol. 59, no. 3, pp. 433–450.
- Adamczewski, A., Hertzog, T., Dosso, M., Jouve, P. and Jamin, J.-Y. (2011) 'L'irrigation peut-elle se substituer aux cultures de décrue ? La dépression du lac Horo (Nord Mali)', *Cahiers Agricultures*, vol. 20, no. 1, pp. 97–104.
- Akande, G. and Diei-Ouadi, Y. (2010) *Post-Harvest Losses in Small-Scale Fisheries: Case Studies in Five Sub-Saharan African Countries*. FAO Fisheries and Aquaculture Technical Paper, No. 550, FAO.
- Akyeampong, E. (2007) 'Indigenous knowledge and maritime fishing in West Africa: the case of Ghana', *Tribes and Tribals*, vol. 1, pp. 173–182.
- Allison, E.H. (2011) *Aquaculture, Fisheries, Poverty and Food Security*. Working Paper 2011–65, The WorldFish Center, Penang.
- Andrefouet, S., Guillaume, M.M., Delval, A., Rasoamanendrika, F.M.A., Blanchot, J. and Bruggemann, J.H. (2013) 'Fifty years of changes in reef flat habitats of the Grand Récif de Toliara (SW Madagascar) and the impact of gleaning', *Coral Reefs*, vol. 32, no. 3, pp. 757–768.
- Atta-Mills, J., Alder, J. and Sumaila, U.R. (2004) 'The decline of a regional fishing nation: the case of Ghana and West Africa', *Natural Resources Forum*, vol. 28, pp. 13–21.
- Avery, S. (2013) *What Future for Lake Turkana? The Impact of Hydropower and Irrigation on the World's Largest Desert Lake*. University of Oxford African Studies Centre.
- Bakari, S.S., Aagaard, P., Vogt, R.D., Ruden, F., Johansen, I. and Vuai, S.A. (2012) 'Delineation of groundwater provenance in a coastal aquifer using statistical and isotopic methods, Southeast Tanzania', *Environmental Earth Sciences*, vol. 66, no. 3, pp. 889–902.
- Barbier, B., Ouedraogo, H., Dembélé, Y., Yacouba, H., Barry, B. and Jamin, J.Y. (2011) 'L'agriculture irriguée dans le Sahel ouest-africain', *Cahiers Agricultures*, vol. 20, no. 1, pp. 24–33.
- Beale, C.M., Rensberg, S.V., Bond, W.J., Coughenour, M., Fynn, R., Gaylard, A., Grant, R., Harris B., Jones, T., Mduma, S., Owen-Smith, N. and Sinclair, A.R. (2013) 'Ten lessons for the conservation of African savannah ecosystems', *Biological Conservation*, vol. 167, pp. 224–232.
- Béné, C. and Friend, R.M. (2011) 'Poverty in small-scale fisheries old issue, new analysis', *Progress in Development Studies*, vol. 11, no. 2, pp. 119–144.
- Béné, C., Hersoug, B. and Allison, E.H. (2010a) 'Not by rent alone: analysing the pro-poor functions of small-scale fisheries in developing countries', *Development Policy Review*, vol. 28, no. 3, pp. 325–358.
- Béné, C., Lawton, R. and Allison, E.H. (2010b) 'Trade matters in the fight against poverty: narratives, perceptions, and (lack of) evidence in the case of fish trade in Africa', *World Development*, vol. 38, no. 7, pp. 933–954.
- Béné, C., Neiland, A., Jolley, T., Ovie, S., Sule, O., Ladu, B., Mindjimba, K., Belal, E., Tiotsop, F., Baba, M. Dara, L., Zakara, A. and Quensiére, J. (2003) 'Inland fisheries, poverty, and rural livelihoods in the Lake Chad Basin', *Journal of Asian and African Studies*, vol. 38, no. 1, pp. 17–51.
- Béné, C., Steel, E., Luadia, B. K. and Gordon, A. (2009) 'Fish as the "bank in the water": evidence from chronic-poor communities in Congo', *Food Policy*, vol. 34, no. 1, pp. 108–118.
- Bennett, E. (2005) 'Gender, fisheries and development', *Marine Policy*, vol. 29, pp. 451–459.
- Brashares, J.S., Arcese, P., Sam, M.K., Coppoillo, P.B., Sinclair, A.R.E. and Balmford, A. (2004) 'Bushmeat hunting, wildlife declines, and fish supply in West Africa', *Science*, vol. 306, no. 5699, pp. 1180–1183.
- Chauveau, J.-P. and Jul-Larsen, E. (2000) 'Du paradigme halieutique à l'anthropologie des dynamiques institutionnelles', in Chauveau, J.-P., Jul-Larsen, E. and Chaboud, C. (eds) *Les pêches piroguères en Afrique de l'Ouest. Dynamiques institutionnelles: pouvoirs, mobilités, marches*. Karthala, pp. 9–85.

- Cinner, J.E., McClanahan, T.R., Daw, T.M., Graham, N.A.J., Maina, J., Wilson, S.K. and Hughes, T.P. (2009) 'Linking social and ecological systems to sustain coral reef fisheries', *Current Biology*, vol. 19, pp. 206–212.
- Cinner, J.E., McClanahan, T.R., Graham, N.A.J., Daw, T.M., Maina, J., Dtead, S.M., Wamukota, A., Brown, K. and Bodin, Ö. (2012) 'Vulnerability of coastal communities to key impacts of climate change on coral reefs fisheries', *Global Environmental Change*, vol. 22, pp. 12–20.
- Comas, J., Connor, D., Isselmou, M.E.M., Mateos, L. and Gómez-Macpherson, H. (2012) 'Why has small-scale irrigation not responded to expectations with traditional subsistence farmers along the Senegal River in Mauritania?' *Agricultural Systems*, vol. 110, pp. 152–161.
- Cormier-Salem, M.C. (ed.) (1999) *Rivières du Sud: Sociétés et mangroves ouest-africaines*. IRD Éditions.
- Crona, B. and Rosendo, S. (2011) 'Outside the law? Analyzing policy gaps in addressing fishers' migration in East Africa', *Marine Policy*, vol. 35, pp. 379–388.
- De Graaf, G.J., Grainger, R.J., Westlund, L., Willmann, R., Mills, D., Kelleher, K. and Koranteng, K. (2011) 'The status of routine fishery data collection in Southeast Asia, central America, the South Pacific, and West Africa, with special reference to small-scale fisheries', *ICES Journal of Marine Science*, vol. 68, no. 8, pp. 1743–1750.
- De Groot, R., Brander, L., Van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., Ten Brink, P. and Van Beukering, P. (2012) 'Global estimates of the value of ecosystems and their services in monetary units', *Ecosystem Services*, vol. 1, no. 1, pp. 50–61.
- Deininger, K.W. and Byerlee, D. (2011) *Rising Global Interest in Farmland: Can It Yield Sustainable and Equitable Benefits?* World Bank.
- De la Croix, K., Dao, A., Ferry, L. Landy, F. Muther, N. and Martin, D. (2014) 'Les systèmes de pêches collectives fluviales somono dans le Manden (Mali): Un révélateur territorial et social unique en sursis sur le Niger supérieur', in Ferry L. and Mietton M. (eds) *Chemins et territoires de l'eau dans les pays de la ceinture tropicale. Ressources et patrimoines, Dynamiques Environnementales*, vol. 32, pp. 125–143.
- Dickmann, M., Ficatier, M. and Schmidt, M. (2009) *Le Barrage de Manantali. Evaluation ex-post conjointe*. Rapport de synthèse Coopération financière avec l'Organisation pour la Mise en Valeur du fleuve Sénégal (OMVS), Banque allemande de développement (KfW), Banque européenne d'investissement (BEI), Agence française de développement (AFD).
- Duvail, S. and Hamerlynck, O. (2003) 'Hydraulic modelling as a tool for the joint management of a restored wetland: sharing the benefits of managed flood releases from the Diamas dam reservoir', *Hydrology and Earth System Sciences*, vol. 7, no. 1, pp. 133–146.
- Duvail, S. and Hamerlynck, O. (2007) 'The Rufiji River flood: plague or blessing?' *International Journal of Biometeorology*, vol. 52, pp. 33–42.
- Duvail, S., Hamerlynck, O., Paron, P., Hervé, D., Nyingi, D.W. and Leone, M. (2017) 'The changing hydro-ecological dynamics of rivers and deltas of the Western Indian Ocean: Anthropogenic and environmental drivers, local adaptation and policy response'. *Comptes Rendus Geoscience*, vol. 349, no 6, pp. 269–279.
- Duvail, S., Médard, C., Hamerlynck, O. and Nyingi, D.W. (2012) 'Land and water "grabbing" in an East African coastal wetland: the Tana Delta case study', *Water Alternatives*, vol. 5, no. 2, pp. 322–343.
- Duvail, S., Mwakalinga, A., Eijkelenburg, A., Hamerlynck O., Kindinda, K. and Majule, A. (2014) 'Jointly thinking the post-dam future: exchange of local and scientific knowledge on the lakes of the Lower Rufiji, Tanzania', *Hydrological Sciences Journal*, vol. 59, no. 3–4, pp. 713–730.
- Ellis, F. (1998) 'Household strategies and rural livelihood diversification', *The Journal of Development Studies*, vol. 35, no. 1, pp 1–38.
- Eriksson, H. (2012) 'Managing sea cucumber fisheries and aquaculture: studies of social-ecological systems in the Western Indian Ocean'. Unpublished PhD thesis, Stockholm University.
- FAO (2012) *The Status of World Fisheries and Aquaculture 2012*. Food and Agriculture Organisation of the United Nations.

- FAOSTAT (undated) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- Feka, N.Z. and Manzano, M.G. (2008) 'The implications of wood exploitation for fish smoking on mangrove ecosystem conservation in the south west province, Cameroon', *Tropical Conservation Science*, vol. 1, no. 3, pp. 222–241.
- Fröcklin, S., De la Torre-Castro, M., Lindström, L., Jiddawi, N.S. and Msuya, F.E. (2012) 'Seaweed mariculture as a development project in Zanzibar, East Africa: a price too high to pay?' *Aquaculture*, vol. 356, pp. 30–39.
- Geheb, K. and Binns, T. (1997) "Fishing farmers" or "farming fishermen"? The quest for household income and nutritional security on the Kenyan shores of Lake Victoria', *African Affairs*, vol. 96, no. 382, pp. 73–93.
- Geheb, K. and Crean, K. (2003) 'Community-level access and control in the management of Lake Victoria's fisheries', *Journal of Environmental Management*, vol. 67, no. 2, pp. 99–106.
- Hall, R. (2011) 'Land grabbing in Southern Africa: the many faces of the investor rush', *Review of African Political Economy*, vol. 38, no. 128, pp. 193–214.
- Hamerlynck, O. and Duvail, S. (2003) *The Rehabilitation of the Delta of the Senegal River in Mauritania: Fielding the Ecosystem Approach*. IUCN Gland.
- Hamerlynck, O., Duvail, S., Vandepitte, L., Kindinda, K., Nyingi, D.W., Paul, J.L., Yanda, P.Z., Mwakalinga, A.B., Mgaya, Y.D. and Snoeks, J. (2011) 'To connect or not to connect? Floods, fisheries and livelihoods in the Lower Rufiji floodplain lakes, Tanzania', *Hydrological Sciences Journal*, vol. 56, no. 8, pp. 1436–1451.
- Hamerlynck, O., Moulaye Zeine, S.A., Mutua J.Y., Mukhwana, L.V. and Yena, M. (2016) 'Reflooding the Faguibine System in Northern Mali: potential benefits and challenges', *African Journal of Aquatic Science*, vol. 41, no. 1, pp. 109–117.
- Hardin, G. (1968) 'The tragedy of the commons', *Science*, vol. 162, no. 3859, pp. 1243–1248.
- Harrison, L.E. and Huntington, S.P. (2000) *Culture Matters: How Values Shape Human Progress*. Basic Books.
- Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A. and Hatzioiols, M.E. (2007) 'Coral reefs under ocean acidification under rapid climate change', *Science*, vol. 318, pp. 1737–1742.
- Jacob, J.-P. (2003) *Fishing Rights on the Floodplains of Gwendégoué, Winye Country, Central Western Burkina Faso*. IIED Issue Paper No. 121.
- Kipkemboi, J., van Dam, A.A., Ikiara, M.M. and Denny, P. (2007) 'Integration of smallholder wetland aquaculture–agriculture systems (fingerponds) into riparian farming systems on the shores of Lake Victoria, Kenya: socio-economics and livelihoods', *The Geographical Journal*, vol. 173, pp. 257–272.
- Kolding, J. and van Zwieten, P.A.M. (2011) 'The tragedy of our legacy: how do global management discourses affect small scale fisheries in the South', *Forum for Development Studies*, vol. 38, no. 3, pp. 267–297.
- Kolding, J. and van Zwieten, P.A.M. (2012) 'Relative lake level fluctuations and their influence on productivity and resilience in tropical lakes and reservoirs', *Fisheries Research*, vol. 115, pp. 99–109.
- Kolding, J. and van Zwieten, P.A.M. (2014) 'Sustainable fishing in inland waters', *Journal of Limnology*, vol. 73, pp. 128–144.
- Kolding, J., van Zwieten, P., Mkumbo, O., Silsbe, G. and Hecky, R. (2008) 'Are the Lake Victoria fisheries threatened by exploitation or eutrophication? Towards an ecosystem-based approach to management', in G. Bianchi and H.R. Skjoldal (eds) *The Ecosystem Approach to Fisheries*. CABI, pp. 309–350.
- Komakech, H.C., van Der Zaag, P. and van Koppen, B. (2012) 'The last will be first: water transfers from agriculture to cities in the Pangani river basin, Tanzania', *Water Alternatives*, vol. 5, no. 3, pp. 700–720.
- Maltby, E. and Acreman, M.C. (2011) 'Ecosystem services of wetlands: pathfinder for a new paradigm', *Hydrological Sciences Journal*, vol. 56, no. 8, pp. 1341–1359.

- Margulis, M.E., McKeon, N. and Borras, S.M. Jr. (2013) 'Land grabbing and global governance: critical perspectives', *Globalizations*, vol. 10, no. 1, pp. 1–23.
- Marquette, C.M., Koranteng, K.A., Overå, R. and Aryeetey, E.B.D. (2002) 'Small-scale fisheries, population dynamics, and resource use in Africa: the case of Moree, Ghana', *AMBIO: A Journal of the Human Environment*, vol. 31, no. 4, pp. 324–336.
- Matsuoka, T., Nakashima, T. and Nagasawa, N. (2005) 'A review of ghost fishing: scientific approaches to evaluation and solutions', *Fisheries Science*, vol. 71, pp. 691–702.
- McClanahan, T.R., Graham, N.A., MacNeil, M.A., Muthiga, N.A., Cinner, J.E., Bruggemann, J.H. and Wilson, S.K. (2011) 'Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries', *Proceedings of the National Academy of Sciences*, vol. 108, no. 41, pp. 17230–17233.
- McClanahan, T.R., Graham, N.A.J., Wilson, S., Letourner, Y. and Fisher, R. (2009) 'Effects of fisheries closure size, age, and history of compliance on coral reef fish communities in the western Indian Ocean', *Marine Ecology Progress Series*, vol. 396, pp. 99–109.
- Mehta, L., Veldwisch, G.J. and Franco, J. (2012) 'Introduction to the special issue: Water grabbing? Focus on the (re)appropriation of finite water resources', *Water Alternatives*, vol. 5, no. 2, pp. 193–207.
- Mmopelwa, G. and Ngwenya, B.N. (2010) 'Constraints and potentials of the fish market in the Okavango Delta, Botswana', *African Journal of Agricultural Research*, vol. 5, no. 23, pp. 3176–3184.
- Mölsä, H., Reynolds, J.E., Coenen, E.J. and Lindqvist, O.V. (1999) 'Fisheries research towards resource management on Lake Tanganyika', *Hydrobiologia*, vol. 407, pp. 1–24.
- Müller, C., Cramer, W., Hare, W.L. and Lotze-Campen, H. (2011) 'Climate change risks for African agriculture', *Proceedings of the National Academy of Sciences*, vol. 108, no. 11, pp. 4313–4315.
- Munga, C., Ndegwa, S., Fulanda, B., Manyala, J., Kimani, E., Ohtomi, J. and Vanreusel, A. (2012) 'Bottom shrimp trawling impacts on species distribution and fishery dynamics: Ungwana Bay fishery Kenya before and after the 2006 trawl ban', *Fisheries Science*, vol. 78, no. 2, pp. 209–219.
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A.B. and Kent, J. (2000) 'Biodiversity hotspots for conservation priorities', *Nature*, vol. 403, pp. 853–858.
- Nelson, G.C., Bennett, E., Berhe, A.A., Cassman, K., DeFries, R.S., Dietz, T., Dobermann, A., Dobson, A., Janetos, A., Levy, M.A., Marco, D., Nakicenovic, N., O'Neill, B., Norgaard, R., Petschel-Held, G., Ojima, D., Pingali, P., Watson, R. and Zurek, M. (2006) *Anthropogenic Drivers of Ecosystem Change: an Overview*. Columbia University Academic Commons, <http://dx.doi.org/10.7916/D8125RDD>.
- Njock, J.C. and Westlund, L. (2010) 'Migration, resource management and global change: experiences from fishing communities in West and Central Africa', *Marine Policy*, vol. 34, no. 4, pp. 752–760.
- Nunan, F. (2010) 'Mobility and fisherfolk livelihoods on Lake Victoria: implications for vulnerability and risk', *Geoforum*, vol. 41, no. 5, pp. 776–785.
- Odada, E.O., Olago, D.O., Kulindwa, K., Ntiba, M. and Wandiga, S. (2004) 'Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy options analyses', *AMBIO: A Journal of the Human Environment*, vol. 33, no. 1, pp. 13–23.
- Ostrom, E. (1990) *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press.
- Parnell, S. and Walawege, R. (2011) 'Sub-Saharan African urbanisation and global environmental change', *Global Environmental Change*, vol. 21, pp. S12–S20.
- Paul, J.-L., Duvail, S. and Hamerlynck, O. (2011) 'Appropriation des ressources "naturelles" et criminalisation des communautés paysannes. Le cas du Rufiji, Tanzanie', *Civilisations*, vol. 60, no. 1, pp. 143–175.
- Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R. and Zeller, D. (2002) 'Towards sustainability in world fisheries', *Nature*, vol. 418, pp. 689–695.

- Pinto, R., De Jonge, V.N. and Marques, J.C. (2014) 'Linking biodiversity indicators, ecosystem functioning, provision of services and human well-being in estuarine systems: application of a conceptual framework', *Ecological Indicators*, vol. 36, pp. 644–655.
- Ratner, B.D. and Allison, E.H. (2012) 'Wealth, rights, and resilience: an agenda for governance reform in small-scale fisheries', *Development Policy Review*, vol. 30, no. 4, pp. 371–398.
- Richmond, M.D., Wilson, J.D.K., Mgaya, Y.D. and Le Vay, L. (2002) 'An analysis of smallholder opportunities in fisheries, coastal and related enterprises in the floodplain and delta areas of the Rufiji River, Tanzania', *Rufiji Environment Management Project. REMP Technical Report*, No. 25.
- Ringold, P.L., Boyd, J., Landers, D. and Weber, M. (2013) 'What data should we collect? A framework for identifying indicators of ecosystem contributions to human well-being', *Frontiers in Ecology and the Environment*, vol. 11, pp. 98–105.
- Robertson, S.A. and Luke, W.R.Q. (1993) *Kenya Coastal Forests: The Report of the NMK/WWF Coast Forest Survey*. WWF Project 3256, Coast Forest Status, Conservation and Management.
- Samoilys M.A. and Kanyange N.W. (2008) *Natural Resource Dependence, Livelihoods and Development: Perceptions from Tanga, Tanzania*. IUCN.
- Scholes, R., Hassan, R. and Ash, N.J. (2005) *Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Current State and Trends*. Island Press.
- Seeley, J.A. and Allison, E.H. (2005) 'HIV/AIDS in fishing communities: challenges to delivering antiretroviral therapy to vulnerable groups', *AIDS Care: Psychological and Socio-medical Aspects of AIDS/HIV*, vol. 17, no. 6, pp. 688–697.
- Shanahan, T.M., Overpeck, J.T., Anchukaitis, K.J., Beck, J.W., Cole, J.E., Dettman, D.L., Peck, J.A., Scholz, C.A. and King, J.W. (2009) 'Atlantic forcing of persistent drought in West Africa', *Science*, vol. 324, pp. 377–380.
- Smith, S.V. (1978) 'Coral-reef area and the contributions of reefs to processes and resources of the world's oceans', *Nature*, vol. 273, no. 5659, pp. 225–226.
- Spalding, M.D., Ravilious, C. and Green, E.P. (2001) *World Atlas of Coral Reefs*. University of California Press.
- Steneck, R.S. (2009) 'Marine conservation: moving beyond Malthus', *Current Biology*, vol. 19, no. 3, pp. R117–R119.
- Thiollay, J.M. (2006) 'Large bird declines with increasing human pressure in savanna woodlands (Burkina Faso)', *Biodiversity & Conservation*, vol. 15, no. 7, pp. 2085–2108.
- Tockner, K. and Stanford, J.A. (2002) 'Riverine floodplains: present state and future trends', *Environmental Conservation*, vol. 29, pp. 308–330.
- Turpie, J., Smith, B., Emerton, L. and Barnes, B. (1999) *Economic Value of the Zambezi Basin Wetlands*. IUCN Southern Africa.
- Turpie, J.K. (2000) 'The use and value of natural resources of the Rufiji floodplain and delta, Tanzania', *Rufiji Environment Management Project Technical Report 17*, Dar es Salaam.
- Tweddle, D. (2010) 'Overview of the Zambezi River System: its history, fish fauna, fisheries, and conservation', *Aquatic Ecosystem Health & Management*, vol. 13, no. 3, pp. 224–240.
- United Nations, Department of Economic and Social Affairs, Population Division (2013) *World Population Prospects: The 2012 Revision, Volume I: Comprehensive Tables ST/ESA/SER.A/336*.
- van den Bossche, P. and Delespau, V. (2011) 'Options for the control of tsetse-transmitted livestock trypanosomosis. An epidemiological perspective', *Veterinary Parasitology*, vol. 181, no. 1, pp. 37–42.
- Wamukota, A.W., Cinner, J.E. and McClanahan, T.R. (2012) 'Co-management of coral reef fisheries: a critical evaluation of the literature', *Marine Policy*, vol. 36, no. 2, pp. 481–488.
- Weeratunge, N., Béné, C., Siriwardane, R., Charles, A., Johnson, D., Allison, E.H., Nayak, P.K. and Badjeck, M.-C. (2013) 'Small-scale fisheries through the wellbeing lens', *Fish and Fisheries*, vol. 15, no. 2, pp. 255–279.
- Welcomme, R. (2008) 'World prospects for floodplain fisheries', *Ecology & Hydrobiology*, vol. 8, nos. 2–4, pp. 169–182.

- Welcomme, R.L., Cowx, I.G., Coates, D., Béné, C., Funge-Smith, S., Halls, A. and Lorenzen, K. (2010) 'Inland capture fisheries', *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 365, no. 1554, pp. 2881–2896.
- Weyl, O.L., Ribbink, A.J. and Tweddle, D. (2010) 'Lake Malawi: fishes, fisheries, biodiversity, health and habitat', *Aquatic Ecosystem Health & Management*, vol. 13, no. 3, pp. 241–254.
- Woodhouse, P. (2012) 'Foreign agricultural land acquisition and the visibility of water resource impacts in Sub-Saharan Africa', *Water Alternatives*, vol. 5, no. 2, pp. 208–222.
- World Bank (2009) *Awakening Africa's Sleeping Giant: Prospects for Commercial Agriculture in the Guinea Savannah Zone and Beyond – Directions in Development*. World Bank and FAO.
- World Commission on Dams (2000) *Dams and Development: A New Framework for Decision-Making*. London.
- Zwarts, L., Beukering, P.V., Kone, B. and Wymenga, E. (2005) *The Niger, a Lifeline: Effective Water Management in the Upper Niger Basin*. RIZA, Lelystad.
- Zwieten, P.V., Béné, C., Kolding, J., Brummett, R. and Valbo Jorgensen, J. (eds) (2011) *Review of Tropical Reservoirs and Their Fisheries in Developing Countries: The Cases of the Lake Nasser, Lake Volta and Indo-Gangetic Basin Reservoirs*. FAO Fisheries and Aquaculture Technical Paper 557, FAO.

12 The forest-based farming system

Highly diverse, annual and perennial systems under threat

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Key messages

- The African forest-based farming system (FBFS) is the starting point for most humid zone farming systems; it only exists at low population densities and, depending on population growth, is a relatively short transition phase into more sedentary systems with higher levels of specialization.
- FBFS provide a wide range of food and non-food products for many of which no alternative sources exist.
- FBFS farmers are highly food secure yet poorly connected to markets and service providers, thus severely cash-constrained and suffering from a lack of financial, medical, educational and social services rendering families vulnerable and cut off from urban employment opportunities.
- Due to low labour input FBFS achieve relatively low crop yields yet they are productive because of their often high soil fertility; they draw heavily on the natural resource base for relatively low outputs.
- FBFS are heavily threatened by land-grabbing attempts of large-scale investors.
- Policies need to address human welfare and conservation / environmental protection issues in parallel with providing technical support to FBFS farmers without leading to a rapid transition into more productive yet less sustainable farming systems.
- Intensification and modernization of FBFS have not received sufficient attention from research and policy makers, yet are a potential way to maintain forest environments combined with agricultural production.

Summary

The forest-based farming system (FBFS) is found in the Congo Basin and in discrete fragments of coastal west Africa. It is a largely transitional phase to more intensive, often less sustainable systems. FBFS are relatively food secure due to all year round production and access to non-timber forest food products. However, poverty is pronounced as a consequence of poor transport infrastructure and market access. Human population movement is a major driver of change. Urbanization could provide large markets for forest farmers, yet poor infrastructure and high transport costs render farmers uncompetitive. A transition

to tree crop systems appears a likely future scenario to improve livelihoods without compromising ecosystem function. To achieve this, farmers require rights to trees on their land, necessitating changes in forestry and land tenure laws and agroforestry policies. Ideally, farmers would receive money for avoiding deforestation and forest degradation (REDD+).

Overall description of the farming system and subsystems

The FBFS is confined to existing forest and forest-savannah mosaic areas in the rainforest (Af) and monsoon (Am) Köppen climate zones. The system is found in the humid forest zone of the Congo Basin, comprising the Democratic Republic of Congo (DRC), Republic of the Congo, southern Cameroon, south-western Central African Republic, Equatorial Guinea and Gabon (Table 12.1). In addition, it exists in pockets in west Africa and remnants in Liberia and Côte d'Ivoire (Figure 12.1). Basic data for the farming system are provided in Table 12.1. The FBFS population, 42 per cent of which is urban based, represents 1.5 per cent of the total estimated population in Africa. FBFS with long fallow cycles are under-represented in statistics as most countries do not account for these areas and they may not be detected by remote sensing (Siebert et al. 2010).

The FBFS constitutes a transition phase from forest to permanent cultivation or short fallow systems, and is characterized by farmers acquiring control over land by clearing thereby acquiring usufruct rights (Figure 12.2). Length of growing period (343 days) distinguishes the FBFS from bordering systems, i.e. the tree crop (299 days; see Chapter 9 this volume) and the root and tuber crop farming systems (269 days; see Chapter 6 this volume). Savannah forest systems such as the Chitemene in Northern Zambia, with much shorter LGP, are not covered by this chapter.

Commonly, the FBFS is rainfed and includes long fallow periods. Intercropping predominates and opportunistic crops (volunteers) are maintained (Büttner and Hauser 2003).

Table 12.1 Basic system data (2015): forest-based farming system

<i>Item</i>	<i>Data</i>
Total human population (million)	18
Agricultural population (million)	12
Total area (million ha)	135
Cultivated area (million ha; % of total area)	0.7; 1
Irrigated area (million ha; % of cultivated area)	0.002; 0
Total livestock population (million TLU)	0.5
Agroecological zone	Tropical warm humid
Length of growing period (average, days ; core range, days)	343; 330–365
Access to services (low/medium/high)	Low
Distance to 50k market (average, hr; core range, hr)	13.7; 6–10+
Agricultural population density (persons/total area; persons/cultivated area)	0.1; 17.2
Livestock density (TLU/total area; TLU/cultivated area)	0.0; 0.7
Standard farm and herd size (cultivated area/household; TLU/household)	0.3; 0.2
Extreme poverty (% of rural population)	52

Source: Refer to Table 2.4.

Figure 12.1 The forest-based farming system in Africa.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Figure 12.2 Bush or early succession clearing where only few and small trees are spared, trunks are laying in the foreground and large trees are left standing. This situation is typical of a transition from forest-based systems with abundant forest around to more intensive root and tuber or maize and vegetable systems.

Source: Stefan Hauser.

Farmers have many household enterprises including hunting and gathering. Most enterprises are gender segregated with food crop fields largely the responsibility of women, yet plantain is a 'man's crop'. Perennial cash crops such as cocoa are usually managed by men. Hunting is a male domain; gathering is done by women and men. The degree of mechanization is low: initial forest clearance is with machetes, occasionally with chainsaws, and fields are hand-hoed. Soils are highly weathered, leached, of low pH and nutrient poor with low cation exchange capacity and often aluminium and manganese toxicity.

Hunting and particularly fishing are still important activities in the rainforest due to the abundance of rivers; however, there is little aquaculture. Forest products and food from non-agricultural natural production are important. In southern Cameroon, mushroom collection has declined in importance, and certain species are no longer found in the more intensively used bush fallow crop rotations. *Termitomyces* spp. mushrooms, tended by *Macrotermes* termites and emerging from their mounds, are a high value commodity. Other important activities are palm oil production from wild oil palms, palm wine production, harvesting of wild honey and collection of edible caterpillars and other insect larvae.

The contribution of forest products to sustaining livelihoods in the FBFS is highlighted in a recent Poverty and Environment Network (PEN) study of more than 8,000 households:

- Forest income constitutes about one fifth of total household income, while environmental income (forest and non-forest) makes up more than one fourth.
- A surprising finding was that overall forest reliance varies little with income levels. Hence, forest income benefits not just the poor but everyone at the study sites.
- Another surprising finding was that forests play much less of a role than previously believed in household safety nets in response to shocks, and in filling recurrent seasonal income gaps.
- Contrary to what has been claimed in other studies, men bring as many or more forest products to the household as women, although there is a clear pattern of women being more involved in subsistence activities and men in cash-earning activities.
- Firewood constitutes the single most important forest product, contributing about one fifth of forest income on average, followed by timber which contributes 10%.
- More than a quarter of all sample households had cleared forest area for crops within the last year of the survey, with the most well-off 20% of households clearing 30% more than the poorest 20%. Such results do not lend support to the hypothesis that poverty drives deforestation.

(CIFOR 2012: 1)

The FBFS may contain tree crops, root and tuber crops, banana and plantain and a wide range of other crops, mainly aroids (tubers), leafy vegetables and local species. Economically, the FBFS has <US\$500 annual marketed tree crop production per household and <20 per cent marketed root and tuber production, which distinguishes it from the tree crop system and root and tuber system, respectively.

Farmers manually clear forest or fallow, let residue dry, then burn and cultivate crops (Figure 12.3). Fields are later abandoned, returned to fallow and new fields are cleared (Hauser and Norgrove 2013). In southern Cameroon, for example, 'essep' fields are established immediately after clearing a primary, secondary forest or tree-dominated old

Figure 12.3 After burning the flimsy plant material, the farmer in this photograph starts to plant small seeded crops (maize, groundnut) in places where little woody residue is left. In places where a lot of woody residues remain (foreground) he is likely to plant plantain and climbing melon, using the trunks and branches as climbing support (no labour used for staking). Cassava will be planted across the whole field.

Source: Stefan Hauser.

fallow (Diaw 1997; Gockowski et al. 2004; Norgrove and Hauser 2015). Typically in the *essep* phase, some trees are retained (Carrière et al. 2002) and shade-tolerant crops such as melon (*Cucumeropsis mannii*), plantain (*Musa* spp AAB), tannia (*Xanthosoma sagittifolium*) and taro (*Colocasia esculenta*) are grown. The *essep* phase is followed by the ‘Afub owondo’ (groundnut field) phase, in which groundnut (*Arachis hypogaea*), often with cassava (*Manihot esculenta*), maize (*Zea mays*) and leafy vegetables as minor components are planted. This field type is as well established after short bush fallow and typically tilled after burning. After harvest, the field is fallowed either for a short period and the ‘afub owondo’ is repeated, or for a long period, re-entering the ‘*essep*’ cycle (Figure 12.4). After many short fallow cycles, grass invasion may render the fallow prone to fires.

There are few cattle and small ruminants due to the high risk of trypanosomiasis (a parasitic disease, also known as sleeping sickness transmitted by the tsetse fly (*Glossina* genus) and caused by protozoans of the genus *Trypanosoma*). However trypanosome-tolerant dwarf goats and sheep are often found free-ranging as well as chickens and pigs.

Egalitarian access to land is common in the FBFS of the Congo Basin. In southern Cameroon villages comprise multiple clans, there is fragmentation of ethnic formations and the concept of ethnicity is complex (Diaw 1997). Before cocoa became a major crop, the clan played a central role in land allocation, but more recently, this influence is less pronounced although the lineage and clan still play a role in structuring access to land

Figure 12.4 A simplified illustration of the fallow-crop dynamic for two major FBFS phases ('essep' and 'afub owondo') in southern Cameroon.

(Russell 1993). Societies are highly egalitarian, based on men's ability to acquire land and provide for their families and thus far less power is vested in chiefs than in the more hierarchical societies of Cameroon's western and northern regions (Russell 1993).

Physical isolation, lack of roads, low quantities of produce and long distances to markets limit trading of agricultural produce and cash generation (Figure 12.5). Poverty is extensive and often severe (Table 12.2); 5.7 per cent and 15.4 per cent of the population are severely and undernourished, respectively.

Subsystems

The two subsystems are strikingly distinguished by the pattern of forest clearing. Other criteria are intensity of clearing or vegetation removal and the technique used to clear (Table 12.3).

Figure 12.5 A rain shelter in the forest about 70 km south of Kikwit in Kwilu province, DRC. The landscape is strongly dissected and fertile forest soils are often found far from the village. Thus people may use the shelter to stay for some days to complete clearing, planting or harvesting operations for a cassava field. From here farmers may arrange transport or sales.

Source: Stefan Hauser.

Table 12.2 Percentage of population earning less than US\$1.25 and less than US\$2.00 per day, based on the area of forest-based farming system per country

<i>Country</i>	<i><\$1.25 / day</i>	<i><\$2.00 / day</i>
Cameroon	55*	—
Central African Republic	64.4	83.2
Republic of the Congo	54.1	74.4
Democratic Republic of Congo	64.9	85.8
Côte d'Ivoire	24.0	52.5
Equatorial Guinea	—	—
Gabon	33**	—
Liberia	86.1	95.6
Mean	52.4	69.1

Notes:

*2001 figures cited in République du Cameroun (2003).

**Ministère de la Planification et de la Programmation du Développement (2005), Enquête Gabonaise pour le suivi et l'évaluation de la pauvreté (EGEP 2005), Rapport sur les indicateurs de base du bien-être, Libreville.

Forest mosaic subsystem

Establishing scattered, small clearings and fallows, along with the cultivation of perennials, creates a mosaic landscape of cropped fields, recently abandoned fields and fields at various levels of bush and forest recovery. The area around Mbalmayo in southern Cameroon is

Figure 12.6 Satellite image of the IITA forest margins benchmark area in southern Cameroon. Note: The high land use intensity around Yaoundé and increasing forest cover along a north-south-transect. Source: SPOT HRV image, March 1995.

a good example of a forest-fallow-crop mosaic landscape (Figure 12.6). Often land tenure is not legally formalized, yet clear rules exist. For example, customary tenure is in force in southern Cameroon but has only semi-legitimate status. While control and tenure in cultivated land adjacent to the homestead is, in most cases, legitimately acknowledged, areas further away, especially fallows, might be the object of disputes (Russell et al. 2011). Such fields may border one another but are most often discrete units. Farmers establish fields along a virtual perimeter to secure access to the inside area. Other farmers are not allowed to establish fields within the area delineated by the outer fringe of a set of clearings belonging to the same family. This leads to establishment of fields at large distances from the homestead with long travelling times to reach sites, yet secures large areas for future use. In a village near Cameroon's capital, Yaoundé, family holdings were 25 ha, on average, while further away from the capital, holdings of >100 ha were recorded (S. Hauser, unpublished).

Contiguous forest fringe subsystem

In the forest of DRC, with low population density, most cropped fields are near roads (Figure 12.7). Dominant crops are plantain and cassava for home consumption and selling to passing vehicles. Fresh produce, processed cassava and forest products including charcoal, are transported by bicycle or canoe to urban centres. When fields adjacent to roads decline in productivity or are invaded by weeds, farmers move away from the road and clear adjacent land. This corridor of cleared land thus widens with the age of the

Figure 12.7 Ongoing clearing along a road at Yamgambi, about 100 km west of Kisangani in the Province Tshopo, DRC. Regardless of road traffic, farmers prefer clearing land close to roads simply to evacuate their produce without maintaining paths to fields further away from the road. It takes only a few months for the bush to close a foot path and plantain and cassava, the major crops of local systems, take a year to reach harvest time.

Source: Stefan Hauser.

Table 12.3 Characteristics of the two subsystems of the forest-based farming system

Characteristic	Forest mosaic	Contiguous forest fringe
Pattern of forest clearing	Small discrete plots, often distant from each other, rarely close to homestead or village. Villages often bordered by perennial plantations retaining forest features (shaded cocoa).	One single clearing starting at the homestead and progressing into the forest, no retention of forest pockets or larger plantations of perennials.
Intensity of clearing	Low: retention of large or useful trees; labour-efficient gradual tree removal over several years and crop cycles.	Higher than in forest mosaic; usually no trees retained.
Intensity of biomass removal	Crop-dependent, often low at first forest clearing; boles and branches retained to rot; firewood is not a constraint.	Crop-dependent, more complete than in forest mosaic; wood removal for charcoal or firewood sales.
Connection to markets	Poor, irregular, or only for specific crops or products.	Medium, more regular, often at close distance to a major transport axis.
Forest resource use	Mainly harvesting of non-timber forest products (NTFPs) (fruits, nuts, honey, mushrooms, rattan) and hunting. Occasional harvesting of valuable timber trees.	Some harvesting of NTFPs and occasional hunting. Valuable timber trees usually not within the area due to previous logging. Charcoal and firewood sales.
Production objectives	Two major objectives: (1) perennials (cocoa) for cash income and (2) food crops for subsistence with excess marketed (plantain, taro, tannia*) or processed (cassava).	Major objective: food crop production with a higher proportion for marketing and processing than in forest mosaic. Minor objective: perennials for cash income.
Land use intensity / frequency	Variable and crop-dependent often related to the yield obtained in previous cropping cycles, i.e. after high yields, land is cropped sooner than when yields were low.	Variable and crop-dependent but likely higher than in forest mosaic due to the more market-oriented production objectives.

*Tannia (*Xanthosoma sagittifolium*) is also known as new cocoyam.

settlement. These corridors are visible near the towns of Ebolowa and Ambam in southern Cameroon (Figure 12.6). Roadsides often do not recover to forest but remain bush or grassland. The system does not create a landscape mosaic. In the latter, the area surrounding clearings provides seed-rain promoting forest succession. In contrast, the contiguous or corridor system creates a clearing front that progresses and does not have large interfaces with the forest because the forest margin is continuously cleared and cropped. Similarly, in the Republic of Congo, a recent study highlighted the importance of roads, although succession did occur, with recovery speed depending on substrate-related site factors (Kleinschroth et al. 2015).

Trends and drivers of change across the system

Population, hunger and poverty

In the period 2000–2010, population growth in the FBFS area was 2.8 per cent p.a. in rural areas and 5.5 per cent p.a. in urban centres. In the next 30 years, the human population in the FBFS is projected to increase from 16.5 to 28 million and the urban component is projected to double. To feed this population, assuming no change in food imports, either more yet unused land needs to be taken into agricultural use, i.e. more forest needs to be cleared and converted, or yields per unit area need to increase significantly, or fallow periods in already used land need to be shortened, so a greater proportion of the land is under crop cultivation at any one time. Laudelout (1990) estimated a critical value for the system's sustainability of 20 people per km² for the Congo Basin, at an average fallow length of 12 years. In the forest margins of Cameroon, the mean fallow period in areas around Yaoundé, with 70–80 persons per km², is 3.9 years (Gockowski et al. 2004). This indicates that fallow length is limiting yields. Ickowitz (2011) found a negative relationship between population density and fallow length in southern Cameroon. Other models have hypothesized a critical threshold of complete system breakdown at 20–30 persons per km². By 2040, the population density is anticipated to increase, on average, to 21 persons per km², which exceeds the threshold at which models predict that the system cannot be sustained without external inputs or management changes. However, population density is spatially variable so the system may continue in more isolated areas. On more fertile alluvial soils, fallows can be shortened to three to five years without significant yield loss if amended with manure or incorporated crop residue. On the typically acid, leached, red ferralitic soils of the forest, short fallows do not restore soil fertility completely, restricting crop choice often to cassava that can still be grown, although with low yields. This situation would be less severe if external inputs, mainly fertilizer and improved crop varieties, were available or if more complex systems with livestock integration were used to generate manure to maintain soil fertility. Families living in short fallow dominated former forest areas are chronically food insecure, with high levels of malnutrition, particularly in children and pregnant women.

For 1990–2004, per capita annual growth in total food production was 1.6 per cent in the Central African Republic (the highest for the Congo Basin countries), 0.7 per cent for Cameroon and negative in DRC (–4.5%), Republic of Congo (–0.7%) and probably also in Equatorial Guinea and Gabon, which import more than two-thirds of their food. Thus in the Congo Basin countries, total growth in food production is half or less than half that of population growth. Nin-Pratt et al. (2011) calculated that the monetized per capita agricultural output in central Africa declined between 1961 and 2006. Agricultural markets exist but are increasingly being supplied from imports.

Natural resources and climate

Deforestation

Natural resource endowment is good in forested areas, but forest clearing causes rapid decline. Mayaux et al. (2013) have calculated changes in tropical rainforest in Africa, roughly representing the FBFS region, and estimated average net deforestation rates of 0.16 per cent p.a. in central Africa and 0.91 per cent p.a. in west Africa from 1990–2000.

From 2000–2010, average net deforestation rates were reduced to 0.1 per cent p.a. and 0.3 per cent p.a. for central and west Africa, respectively.

There are two sources of deforestation: logging and clearing for agriculture. Logging is deforestation, often only removing a few trees, yet causing extensive damage to the forest by constructing roads and dragging and storing logs. Clearing for agriculture may be utterly disconnected from this, as is the case in the typical forest mosaic clearings (Table 12.3). However, in many places the damaged areas are used by migrant farmers to establish fields as the machines have done (inadvertently) some of the clearing. This opportunistic forest conversion is de facto caused by the exploitation of logging concessions and road construction into the forest. The highest densities of logging roads are in Cameroon and Equatorial Guinea. The most rapidly changing area is in the northern Republic of the Congo, where the rate of road construction roughly quadrupled between 1976 and 1990 and 2000 to 2002. In DRC, containing 63 per cent of the region's remaining forest, Laporte et al. (2007) provide evidence of increasing rates of logging-road construction since 1986.

Transformation of the FBFS is also driven by increased land use intensity and frequency. Fallows are cleared earlier, for example after 4–5 years rather than 15–25 years, reducing the ability of the ecosystem to recover, amplified by successively shorter fallow cycles. Another land use intensification strategy is complete tree clearance: complete burning of slashed material and removal of all residues and other biomass (tree stumps, weeds, crop residues) from fields to facilitate tillage. The negative impacts of tillage on soil, notably on soil organic matter content, become more pronounced with more cropping cycles. Tillage combats weeds, incorporates ash and, by mounding or ridging, concentrates the usually shallow topsoil around the crops. Each of these intensification steps reduces the possibility of returning to forest and increases the probability of switching to grassland.

Climate change

West and central Africa are considered susceptible to climate change given a high dependence upon rain fed agriculture. The major global circulation models predict increases in temperature and precipitation for the humid forest zones (Boko et al. 2007; Waha et al. 2013), yet models are disparate with high uncertainty due to a lack of ground-based data (Washington et al. 2013). There are no proven mitigation and adaptation strategies in place.

Energy

The FBFS is one of the least reliant on fossil fuel. Because use of inputs is very low, world oil markets only impact via transport costs. High fossil fuel prices could have a positive impact on household income because alternative energy sources, such as firewood and charcoal, which are FBFS products, may increase in demand and price, but only near cities, given they are low-value bulky commodities and transport costs are high. Farmers burn wood in their fields after clearing, mainly to remove obstacles to planting and weed control (Büttner and Hauser 2003), so no or reduced burning practices would increase the amount of firewood available and thus could increase income generation. Total wood production in Nigeria and DRC is approximately 800 million m³, with >95 per cent being firewood (Agrawal et al. 2013).

Science and technology

The FBFS has not received sufficient research attention. Civil unrest and war (DRC), strong petrol economies (Gabon and Equatorial Guinea) and other non-agricultural income sources (diamonds in Angola) negatively affect interest and investment in the isolated, rural economy. Shifting cultivation has been scape-goated as wasteful and unproductive. Yet, few practicable alternative systems or components have been offered to improve livelihoods and conserve the natural resource base. On the contrary, Sonneveld and Dent (2009) considered the effects of different farming systems upon land degradation. They grouped tree crop and forest-based systems and found that the impact on soil properties was positive whereas the majority of systems tested had a negative impact. Thus the oft-quoted negative connotations associated with FBFS require revision.

The FBFS has suffered the Cassava Mosaic Disease (CMD) pandemic and currently faces the Cassava Brown Streak Disease (CBSD) threat. The success of breeding tolerant and resistant germplasm, which has contributed to yield gains rather than losses since the late 1980s (Ogbe et al. 2005) should be acknowledged. Yet countries with weak extension systems and poor infrastructure cannot easily distribute new varieties. Increased adoption and use of current scientific and technological advances would improve recovery in production.

There are technologies capable of increasing crop yields at relatively low cost and risk. Yields of a major forest-based crop, plantain, can be doubled or tripled by simple sanitation methods which remove root nematodes (Hauser 2007; Hauser et al. 2008b) at practically no cost. Labour-saving fallow species and management practices to increase yields have been tested successfully in farmers' situations (Hauser et al. 2008a). However, it is difficult to reach farmers, and therefore techniques currently used in the FBFS do not reflect the available technologies for the region, retaining a large gap between actual and attainable yields. For plantain, actual yields are less than one-quarter of attainable yields (Norgrove and Hauser 2014).

Fertilizer use in the FBFS is low. West and central African ports have low load capacity and poor road networks so fertilizers are expensive. The low value of crops renders fertilizer use unprofitable, particularly in remote hinterlands. If fertilizers were cheaper, farmers still might not use more unless there was potential to market additional produce or a severe food shortage. Lack of market access will prevent the smallholder from purchasing even subsidized fertilizers.

Markets and trade

Access to markets is poor. Roads are difficult to maintain under high rainfall conditions. Road density is low compared with savannah areas and transport costs are high. Lack of motorized field-to-village transport is a constraint. Farmers focus on transporting produce of high value per unit weight, such as melon seed, NTFPs such as *Irvingia gabonensis* (bush mango), the condiment *Ricinodendron heudelotii*, horticultural crops, smoked fish and game, and coffee and cocoa. With the exception of coffee and cocoa, these commodities have been neglected by research.

In the 'cuvette' area of the DRC, transport is predominantly by canoe. Although river transport is cost efficient, it provides limited access to the hinterland and is not suitable for large-scale movements. However, investment in transport infrastructure

can change market access. For example, the bridge over the River Ntem between Gabon and Cameroon gave access to the lucrative Gabonese food market for southern Cameroonian farmers.

Urban populations in the Congo Basin are increasing at 3–5 per cent per year, and more (5–8 per cent) in already large cities such as Kinshasa, Kisangani, Brazzaville, Pointe Noire, Libreville, Franceville, Port Gentil, Douala and Yaoundé. Urban demand for staple and convenience foods such as eggs, chicken and fish is increasing.

A new driver of change is foreign initiatives for developing large-scale plantations: Rulli et al. (2013) list 414 individual land grabs in Africa greater than 200 ha classified at the country level. Of these, 63 are in countries where the FBFS exists, affecting 11.7 million ha, although the agroecological zone affected is not specified. Rulli et al. (2013) list investors from 24 countries, representing all continents, with oil palm (27 projects, 2.5 million ha) and rice (12 projects, 0.6 million ha) the two most frequently quoted crops. However, they also list two huge proposed investments in the DRC to plant 5 million ha of *Jatropha curcas*, making this the largest crop by area. Often areas of low to medium population density are targeted, frequently in FBFS areas. Risks and opportunities of international land grabs have been outlined by Von Braun and Meinzen-Dick (2009). Such deals may increase the risk of exploitation, yet may create labour opportunities. Social services such as schools and health care facilities may be offered to employees.

Institutions, human capital and policies

Many countries in which the FBFS is important have institutional weaknesses. For example, DRC has little institutional support for agriculture, agricultural research or infrastructure development for rural populations. Farmers have not received relevant information or benefited from technological developments because of weak dissemination. Rural food markets are not well integrated with the rest of the food marketing system. The most likely future scenario is a continuation of the present ‘business as usual’ under which food imports will continue to grow; public expenditure on agriculture will remain <4 per cent of government budgets; institutions supporting agriculture will remain weak; and rural to urban migration, especially of young people, will continue. Lack of institutions to develop human capital is a major constraint to improving livelihoods in the FBFS. Due to remoteness and low density, rural educational facilities are inadequate, and medical facilities are poorly staffed and equipped, and difficult to access.

Most countries in the zone dominated by the FBFS have considerable extractive industries, such as oil, minerals and metal mining. Gabon and Equatorial Guinea are major oil producers and offer employment opportunities. The mining industry in DRC is formally obliged to crop a certain area of their concessions, providing agricultural as well as industrial employment.

Forestry laws restrain the development of the FBFS in some countries. In Cameroon, for example, trees belong to the state and farmers have no legal rights to trees they plant or grow on their land (Robiglio et al. 2013). Legal forest exploitation is confined to logging companies that have obtained concessions and small-scale local loggers with permits. The common practice of felling and selling timber by farmers on their ‘own’ land is actually illegal (Lescuyer et al. 2010; Robiglio et al. 2013). In Cameroon, raw log export restrictions were adopted in 1999 and this has created a local timber milling industry with positive effects on employment and low grade timber availability. The forestry law was changed to give communities the option to submit forest management plans through which villagers would get legal access to and use rights of their communal forest.

Although the process is complicated, many communities have submitted management plans with the help of non-government organizations (NGOs). Robiglio et al. (2010) monitored the situation after the law was revised and assessed the effects on emissions and livelihoods. However, shortly afterwards, with the economic crisis in developed countries, tropical timber purchases declined, many timber mills were closed and the remaining ones ran below capacity.

The logging industry has had a historic role in transforming the FBFS to commercial tree and food crop systems. A classic example was the opening of south-west Côte d'Ivoire forests in the 1970s and 1980s by the logging industry, followed by the 'land belongs to those who develop it' policy of the late president Houphouët-Boigny. Prior to logging these forests, the land was sparsely inhabited by Krou polities. The region was transformed from subsistence agriculture, hunting and gathering to commercial tree crop farming. Labour was mainly supplied by Baoulé and Mossi settlers from Burkina Faso, who negotiated customary use rights to the land. This change was brought about by improved market access due to the logging roads and the laissez-faire land policies of the government, which encouraged immigration into the region. This conflict over resources was at the heart of the recent civil unrest in Côte d'Ivoire.

System and subsystem performance

Productivity

Agricultural productivity of the FBFS is low, reflecting low levels of investment in physical capital (roads, vehicles), natural capital (such as improved Tenera hybrid oil palms, improved varieties of major crops), agricultural inputs (fertilizers, pesticides, machinery) and public services (schools and public health facilities). Crop yield is low although this depends on variety, soil conditions, pest and disease pressure, and labour availability for weeding.

Crop production data are given in Table 12.4. 'Other crops' includes sorghum, millet and wheat; however, data on other crops should be regarded with caution as these crops are outside their ecological range and it is questionable if these data were obtained from fields in the FBFS zone. Banana here only includes sweet or dessert banana and excludes plantain. Cassava, maize, paddy rice and cocoa bean production have not increased greatly

Table 12.4 Total and relative production of major crops in the FBFS, and the range of yields

<i>Crop</i>	<i>Total system production (tonne/year)</i>	<i>Contribution to total system production (%)</i>	<i>Yield range in FBFS (kg/ha)</i>
Cassava	4,063,621	62.63	3,000–45,000
Banana	691,626	10.66	1,500–30,000
Sweet potato / yam	172,564	2.66	yam: 4,000–16,000
Rice	150,720	2.32	500–2,500
Maize	248,273	3.83	500–4,000
Soybean	1,374	0.02	500–2,500
Bean (<i>Phaseolus</i>)	3,701	0.06	500–2,000
Groundnut	45,184	0.69	200–800
Sugarcane	869,683	13.40	
All other crops	241,888	3.72	

Source: FAOSTAT 2012 data average for 2009–2010 based on Harvest Choice 2000 spatial footprint.

Figure 12.8 Production of cassava, maize, paddy rice and cocoa bean crops in Cameroon, Republic of Congo, Equatorial Guinea and DRC.

Source: FAOSTAT 2013 data from Cameroon, Republic of Congo, Equatorial Guinea and DRC.

Note: Y axis is on a logarithmic scale and in 1,000 tonnes.

in Cameroon, Republic of the Congo, Equatorial Guinea and DRC between 1961 and 2011 (Figure 12.8).

In Cameroon and the Central African Republic, agricultural labour productivity increased between the early 1990s and early 2000s, yet it fell in DRC. For most countries, statistics on agricultural revenue per hectare and per worker are not available.

Input use is low and thus very little information exists on the profitability of fertilizer, pesticides, mechanization and other capital investments. In Cameroon, sanitation methods for plantain planting material had high returns to labour (Hauser 2007). Tueche et al. (2013) found that the less labour-intensive manual tillage had higher returns to labour than the more labour-intensive removal of tree stumps to permit tractor tillage in horticultural production in bush fallow/crop rotation systems.

Sustainability

Figure 12.9 demonstrates the relationship between fallow length (cropping frequency) and soil fertility, using three scenarios. In the Congo basin the current land use frequency permits 20 persons per square kilometre to be sustained at long enough fallow phases (Laudelot 1990), equivalent to scenario 1 or 2 in Figure 12.9. If population density exceeds

Figure 12.9 Scenarios in the hypothetical relationship between fallow length and soil fertility (as a proxy for system recovery): 1. cropping frequency low, the length of fallow, essential for full fertility recovery exceeded by a non-essential phase, sustainable; 2. cropping frequency exactly timed to match attainment of maximum fertility; 3. fallow length too short to attain maximum fertility or system recovery.

Source: Hauser et al. (2006), adapted after Guillemin (1956).

this, without intensification, fallows are shortened and yields decline (scenario 3). Although it has been difficult to obtain empirical evidence for the decline at a specified population density, comparing population density and nutrient limitations shows a link (Vanlauwe et al. 2014) that is likely connected to the shortening of fallows, as discussed earlier in the chapter. The general perception is that in early stages of land use intensification and the accompanying degradation, the use of fertilizer, crop residues, manure and planted legume fallow and combinations of mineral fertilizer and organic inputs would maintain crop productivity and soil properties. Such early measures to maintain the soil nutrient and organic matter status are most likely less labour and capital intensive than allowing a long phase of degradation until crop production becomes problematic and unprofitable. Input use at such stages may not increase crop yields as it would in less degraded situations.

Population growth threatens the economic sustainability, profitability and viability of the FBFS, as areas convert to higher land use frequency and intensive systems. Additional risk factors are commercial logging and large-scale development projects, such as land grabs and timber extraction, which decrease the available land for smallholders. In remote communities where there is no alternative to increase cash income, commodity price drops lead to higher household output of such commodities and further decline in price, aggravating the situation for FBFS households.

Although in some countries the legal framework has been changed to improve natural resource management and conservation, enforcement can be difficult. Logging companies are required to replant after logging, but subsequent land uses may obliterate any attempt of reforestation.

Human development outcomes

Farmers and families in the FBFS are generally food secure due to the nearly year-round growing period and the availability of food from non-agricultural sources. However, nutritional quality may be low as most crops are starchy and poor in protein. Poverty *sensu* low cash availability is widespread and one of the factors hampering human development.

There are often limited social services available in FBFS areas (e.g. Russell et al. 2011 for southern Cameroon and DRC). In most countries, education is not free and health care is expensive and difficult to access. The general health status of the population is difficult to assess. However, given the high disease risk in the tropical environment, the high physical workload and poor general living conditions (homes without solid floors, no insect screens, no mosquito nets, no clean drinking water), disease exposure is high. Poor health impedes capacity to work and malaria is frequently encountered. In southern Cameroon, during on-farm research conducted by IITA, it was discovered that farmers take two weeks to recover from malaria and they have multiple attacks per year (J. Gockowski, pers. comm.).

In most cases, access to resources is not a limiting factor, but gender-related access may limit use of some income-generating resources and activities. Hunting, logging and palm wine tapping are frequently male-dominated domains. Forest dwellers are highly skilled with the tools used for agriculture, hunting, fishing, and gathering and exploitation of NTFPs. However, few have other skills due to poor education.

Strategic priorities for the system and pathways out of poverty

Agricultural growth potential is moderate due to the existence of large uncultivated areas and high rainfall, yet yield increases are only expected to be modest. Exploitation of

managed forest products such as timber, rattan and low intensity tree crops in multi-strata systems including food crops at certain stages, may offer sustainable development opportunities. Expansion of agriculture requires careful balancing of the consequences of deforestation, such as loss of biodiversity, soil fertility and wildlife habitats versus the gains through food production.

Five pathways out of poverty were proposed by Dixon et al. (2001). An updated assessment is given in Table 12.5 based on the goal of halving poverty by 2030. Intensification, diversification and exit from agriculture are considered to have the highest probability of success. These pathways are followed by increased farm size, but only if combined with diversification and intensification. The use of labour-saving food production systems (intensification) could free labour for diversification and the cultivation of larger areas. Increased off-farm income is considered the least likely pathway out of poverty because it relies strongly on (foreign) investment in large-scale plantation establishment and the continued logging of timber species. Both large-scale plantations and continued logging appear insufficient to be relevant and reliable off-farm income sources to a substantial proportion of the FBFS population because they are restricted to comparatively small areas (plantations) or are short lived and only locally important (logging). In the new assessment, the largest change is ‘increased farm size’, due to the reduced availability of land.

Intensification

Given poor infrastructure and the low cash availability it appears unlikely that intensification through purchased inputs will be a major pathway to attain higher yields, production and incomes. An alternative pathway is the permanent conversion to planted managed fallows.

With increasing population density, ‘improved’ fallow species such as tree or herbaceous legumes have been tested with the aim of producing biomass at higher rates, fixing nitrogen and smothering weeds better than bush fallows, thus permitting fields to be recropped sooner with no functional loss. Yet, adoption rates are low in Cameroon (Degrande and Duguma 2000; Nolte et al. 2007) and elsewhere. Snapp et al. (2002) demonstrated that soil fertility contributions alone are unlikely to promote adoption if innovations have higher labour requirement than the reference system. Today, given improved participatory research approaches incorporating knowledge of farmers’

Table 12.5 Relative importance of household livelihood improvement strategies

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total ag pop	—	52	48	100
Intensification	2.5	1	2	1.5
Diversification	2	2	3	2.5
Increased farm size	4	1.5	1.5	1.5
Off-farm income	0	2.5	1.5	2
Exit from agriculture	1.5	3	2	2.5

Sources: See Chapter 1, ‘Farm household decisions and strategies’ and Chapter 2, ‘Household strategies’.

resource endowments, specifically labour and adapting to crop and soil requirements, design of appropriate fallow legume systems is possible. Optimally, selected legumes replenish soil fertility in less time, suppress weeds, are easily established, cleared and controlled, re-establish easily after cropping, and neither compete with the crops nor serve as host for pests and diseases. Currently the herbaceous fallows that seem most capable to support food crop production are *Mucuna pruriens* and *Pueraria phaseoloides* (Hauser and Nolte 2002). Yield increases of maize, groundnut and cassava were realized in southern Cameroon after a two-year pueraria fallow (Hauser, unpubl.) while reducing labour requirements. Natural fallow is more labour intensive to clear. In southern Cameroon, maize was grown on the same field for 14 consecutive years by alternating with either a nine-month phase of mucuna or pueraria fallow with maize grain yield maintained at 2.5 t/ha per year (Hauser, submitted).

Another intensification option is the use of herbicides. Considering that weed control requires about 30–60 per cent of smallholder labour in crop production, a reduction in labour time and drudgery to weed fields would free substantial labour for other activities (diversification) or larger operations (increased farm size). Adoption of herbicides may be higher than for managed fallows. Reasons for this are relatively low prices and low bulk of herbicides, thus herbicides are easier to obtain by capital-constrained smallholders in the hinterland. Improved market access would most likely drive the uptake of such technologies. The latter is likely to become more important in the FBFS as urbanization creates demand for staples produced in the hinterland.

Diversification

Although most FBFSs already have high crop diversity and complexity, there are some diversification options that may lead to poverty reduction without compromising environmental services.

Under the restrictive transport and climatic conditions of the FBFS, a commodity must be high value and non-perishable to become a profitable cash crop. Among the highest value crops and commodities of the forest-based farming system are melon seed and seeds of *R. heudelotii*. The latter, a fast-growing pioneer tree species (Norgrove et al. 2002), can produce up to 70 kg of seeds per tree and can be planted at 100 trees per ha. The average expected yield after seven years is approximately 2 to 3 t/ha. Extracting the seed from the pod is laborious and addressing the efficiency of this could improve profitability. With an average price often higher than US\$2.50 per kg in the markets of the sub-region there are potential profits to be made even in the more remote and inaccessible regions of the humid forest. Melon seed has an even higher value and warrants the development of intensified production systems. There has been little research on such crops. Other high-value commodities include bush mango seeds and black pepper (*Piper nigrum*), which is trading at nearly US\$10 per kg on the International Pepper Exchange.

Another diversification option is agrisilviculture. Tree seedlings are planted at the same time as food crops to provide a low competition starting phase for the trees while fully using the land for food production. Additional food crop phases are introduced at regular intervals coinciding with thinning of the tree density during the timber cycle (Norgrove 2003). Agrisilviculture could promote food security and yield marketable timber and fuelwood products, allowing smallholders to escape the 'subsistence crop poverty trap' (Coomes et al. 2011). More widely in west Africa, on-farm timber is recognized as an opportunity to enhance livelihoods and forest

conservation (Robiglio et al. 2011). Integrating crop phases can enhance timber yield (Norgrove and Hauser 2002).

A development in DRC presents a potential win-win situation: logging companies have recently abandoned concessions as forests did not have a sufficient density of marketable boles. Under such conditions, given enabling policies, forest farmers may consider timber production as a long-term and intergenerational strategy out of poverty. Managed plantations, even under agrisilviculture, have a higher potential timber yield than natural forest. Such systems assimilate carbon and store it as wood. If carbon trading systems are developed, carbon credits might be directly marketed, increasing farmers' income.

Another way of system diversification is domestication. Mushrooms could be grown on crop residues and wood from clearings. Honey collection from wild colonies is dangerous, cumbersome and destructive, so setting up beehives would increase production and ease processing. Although animal production is less important (Nielsen et al. 2012), 'bush meat' species such as cane rats (*Thryonomys swinderianus* and *T. gregorianus*) could be raised (Jori and Chardonnet 2001).

Another diversification strategy is the production of charcoal, firewood and construction timber from cleared forest fallow (Figure 12.10). However, this would require changes in legislation, and improvements in transport and trade to distribute produce. This option would not only generate income but could provide employment opportunities for those cutting, processing and charring wood.

Figure 12.10 Initial cropping of plantain after forest clearing. Poor transport infrastructure precludes possibilities for selling wood; thus it remains in the field to rot. The wood is cut up by chainsaw in pieces of a size that allows their movement to keep straight plantain lines. In the foreground the plot has been weeded because hot pepper (*Capsicum* spp) is intercropped, while the operation has not reached the further parts of the field.

Source: Stefan Hauser.

Increased farm size

Ecological considerations apart, expanding the agricultural frontier into ‘unused’ forest may appear a logical way out of poverty from an outsider’s perspective. However, due to limited labour availability, this option may not contribute substantially to poverty reduction or increased food security. Traditional food crop systems are unlikely to play a major role here because they are labour intensive. Only if labour-saving and yield-increasing systems are introduced that reduce or remove the requirement to clear forest, could farmers take larger areas into cultivation. Diversification into tree crops can certainly be coupled with increased farm sizes, but the FBFS would be transformed to a tree crop system. Only the options outlined earlier such as agrisilviculture are likely to expand farmers’ land use while retaining the FBFS.

Increased off-farm income

Off-farm employment and income generation was not previously considered a viable pathway out of poverty (Table 12.5). Typical employers in the past were logging companies looking for scouts on short-term contracts to identify valuable timber trees and casual labour to fell and move boles. Today, with expanding urban populations, there are more jobs in trading. Cheap food imports make forest farmers less competitive, but there are examples of employment creation in landlocked situations through trading agricultural and forest products. In Kisangani, DRC, farmers and transporters have worked out a simple system to supply urban markets. Traders use bicycles to travel long distances (>100 km) to purchase agricultural products at lower farm-gate prices and transport them by pushing the bike to the next major town or river to be sold. Although a slow and labour intensive system, it connects farmers to markets and creates employment. The system is also found in the southern savannahs of Kasai Oriental, DRC. Bicycles have the advantage of being able to pass where motorized vehicles cannot go and any breakdown can be fixed almost anywhere. Institutional weakness has, so far, prevented organized motorized transport which would compete with such manual transport. As such, this lack of development actually provides for relatively equal distribution of income opportunities.

Apart from such local opportunities, off-farm employment has not had much potential as a pathway out of poverty. Today, however, there are more than 1.5 million ha of humid forest targeted by foreign investment (Oxfam 2011). This will have a major impact on FBFS livelihoods (Broughton 2013). It has the potential for land conflict between indigenous users/owners and foreign investors, particularly if a typical capitalist approach of exploiting the weak is implemented. However, there is also the potential for economic and social development through provision of equitable employment, school facilities, medical clinics and other social amenities through the foreign investors. Depending on the type of operation, the investors’ labour demand may absorb all or most of the local labour. The typical industrial oil palm plantation employs one person per 3–5 ha. A 50,000 ha farm would generate jobs for around 10,000 to 15,000 employees. This would provide employment for a population equivalent to 20–33 people per square kilometre, thus for more people than usually living in FBFS-dominated areas. Alternatively, farmers can benefit immediately from satellite or out-grower schemes, established with processing units. Under these arrangements producers agree to sell to processors and processors supply inputs, with credit linked to output sales and extension services. Only if these

large-scale investments are conducted with sufficient consideration of local populations' needs will they contribute to sustainable improvements of livelihoods. They will definitely end the FBFS phase and bring about rapid transition to new systems.

Exit from agriculture

Non-agricultural employment opportunities are scarce in most countries with substantial FBFSs. Forest dwellers have less access to education and therefore fewer employment options. Thus this pathway out of poverty appears less likely. Exiting agriculture is usually coupled with migration to towns. There is evidence of declining populations in the more remote regions of the Congo Basin, showing people are exiting agriculture. However, the rural poor who have open access to local forest resources may face less harsh conditions than the urban poor. No data is available on the proportion of people exiting FBFSs that actually escape poverty. As the better endowed regions of the country intensify their agriculture, those remaining in the FBFS become even more disadvantaged in the market as prices decline with increased production from better-off areas.

Addressing the drivers of change

Population, hunger and poverty

Although population density is low and in some places decreasing, retaining the FBFS requires maintaining an appropriate rural population. Measures to improve livelihoods such as schools, clinics and improved roads could help, yet the costs may be high considering the number of people affected. Without explicit surveys on FBFS farmers' major needs and reasons to exit the system, it is difficult to devise interventions that may keep the population in place. This is especially difficult as the farmers do know about urban life and its advantages. The farmers are aware that urban populations rely on forest-based food and other products, yet they have no leverage to affect prices due to poor transport and market access. Thus an expansion of enabling infrastructure should be of highest priority.

The highest strategic priority for increasing income and reducing poverty by 50 per cent by 2030 in the FBFS of west and central Africa would be to sustainably intensify agriculture, with priority given to food crops which produce a surplus to feed urban populations. This could be supplemented by palm oil, rubber, coffee and cocoa, with the palm oil and rubber coming mainly from nucleus estate schemes under contract, and coffee and cocoa from smallholders for export.

Another strategic priority is encouraging investment in large-scale industrial plantations similar to those in Malaysia but with an emphasis on smallholder contract farming. Indonesia and Malaysia's palm oil production was 50.2 Mt in 2013, generating US\$34 billion dollars of annual producer income from 9.7 million ha in 2009–2011 (FAOSTAT 2012). A substantial portion of this (approximately 30–35 per cent) is produced by smallholders, and the palm oil industry has had a great impact in reducing poverty. In comparison, in DRC, where the hybrid Tenera oil palm was first developed, palm oil production in 2014 was only 215,000 Mt on 178,000 ha of oil palm plantations (Index Mundi 2015). However, DRC has a much larger land resource to expand production – in 2000, it had approximately 125 million ha of dense forest, 23 million ha of agriculture-forest mosaic and 70 million ha of miombo-type (humid savannah) woodlands (Mayaux et al. 2004) on which oil palm could be cultivated. Currently there is no lack of interested investors, yet

there is no lack of controversy over the approach and the consequences (Brautigam 2010), because neither the economic nor the social or environmental impacts of such large-scale conversions have been assessed in central Africa.

Natural resources and climate

There are advantages of different land use options. Forest clearing is labour intensive while bush clearing is relatively easy. However, forest land is preferred by farmers, partly driven by land acquisition goals, but also reflecting its higher productivity (Figure 12.11). On the other hand, intensified production on already-cleared land reduces deforestation.

Within the forest, diversification by inter- or under-planting perennials that can co-exist with forest, such as cocoa, is an option, but the choice of crops is strongly limited. Oil palm and rubber production are based on forest conversion, not on sharing land with food crops, because these species require full sunlight to produce.

The domestication and intensification of niche forest products is another strategy (Agrawal et al. 2013): certain species or products may be developed into income-generating enterprises (domesticated game, termite mushrooms, rattan, wild honey).

Figure 12.11 A new field of maize in southern Cameroon. While in this region traditional cropping patterns dictate that plantain and melon are planted after forest clearing, here farmers chose maize as the first crop. Note the variable performance of the maize crop – somewhat pale and relatively poor performance in the foreground in contrast to the extremely high performance in the centre of the field attaining 4–6 Mg/ha of dry grain yield. The fringe to the still standing forest is unsuitable for maize – the system may get modified by focusing the maize to the centre and have longer-term crops such as plantain, cassava and yam closer to the forest.

Source: Stefan Hauser.

Such activities could also be integrated with large-scale industrial plantations but would require stronger regulation and better informed site selection. Poor implementation of existing environmental protection policies (see institutions and policies) may lead to environmental damage if companies are allowed to follow principles of profit maximization only.

Although global concerns have led to initiatives such as the Rio summit in 1992 (United Nations 1997), the Kyoto protocol (Mrunal 2012) and the Rio + 20 summit, few changes are directly targeting the FBFS and livelihoods of FBFS households. Nevertheless, reducing emissions from deforestation and forest degradation (REDD+) policies to reduce deforestation are gaining importance and especially in the Congo Basin, and funds are becoming available to implement them. The major challenge is to ensure that funds reach local forest dwellers so they have an incentive to reduce forest clearing, shifting cultivation, and slash and burn land preparation and to move towards intensified farming systems that produce less CO₂ and so called greenhouse gases, while retaining more forest to sequester carbon.

Energy

Many cities in the FBFS area are not adequately served by an electricity grid or fossil fuel-based energy carriers. Firewood and charcoal are sources of revenue for FBFS farmers and the cities' energy demands are likely to increase. While this offers a short-term opportunity to FBFS dwellers, a major priority for governments is to bring power to the FBFS areas. Otherwise, it is expected that forest resources will be consumed to meet the countries' energy requirements. An opportunity is exploitation of water resources and other renewable energy sources to electrify urban centres and rural areas. For example, DRC has 60 per cent of Africa's hydroelectric potential with the new Grand Inga dam planned to generate 45,000 MW (Green et al. 2015).

A secondary priority is regional integration to refine petroleum, given that Gabon, Equatorial Guinea, Republic of Congo and DRC are petroleum-producing and exporting countries. Although this may not lead to lower fuel costs, it may contribute to improved transport by increasing fuel availability.

Human capital and information

Education and raising awareness appear the major strategic priorities. School enrolment is low in FBFS-dominated areas (see Mabika and Shapiro 2012 for DRC). Improved educational services would increase options available to farmers, as would access to agricultural extension services.

Science and technology

Technology use in the FBFS does not reflect the technologies available. Reasons for non-uptake need to be identified and technologies modified accordingly. The importance of generating income and improving market access needs to be considered at the outset of technology development. Collaboration between biophysical and socioeconomic sciences is required to 'shape' technologies according to demand and resource endowment. This includes integrating new crops or enterprises. Technology and science need to induce positive change through coordinated interventions, knowledge sharing and market intelligence. The Consultative Group for International Agricultural Research Research programme on Integrated Systems for the Humid Tropics, referred to as *Humidtropics*, is an example of such an approach (IITA 2017).

Markets and trade

There is an urgent need for infrastructure development to improve farmers' access to urban markets. This is particularly important for highly perishable products, which are often more appreciated than the usual staples and thus fetch higher prices. Farmers also have limited access to information (TV, radio, mobile phones) that could potentially improve their participation in marketing and trading.

Institutions and policies

Generally governments need to invest more in agriculture, agricultural research and extension services, particularly in those countries such as DRC with high food insecurity and increased hunger indices since the late 1990s. Yet none is near the 10 per cent budget allocation pledged to agriculture in the Maputo commitment (Leather 2009).

The legal frameworks enhancing rights to forest resources and planted trees and encouraging investment in timber production and NTFPs need urgent improvement or better implementation. Infrastructure (roads, schools, health care, electricity) is typically the domain of governments and as such the governments are called upon to provide FBFS areas with better services. Among the services, agricultural extension is the most important to improve FBFS livelihoods. Medical care is lacking and required. Land use planning which centres on human and rural development must be part of rural development strategies (Russell et al. 2011).

System conclusion

FBFSs are largely transitional phases to other, generally more intensive, often less sustainable systems. Although population growth in regions with predominantly FBFSs is among the lowest in Africa, it is still positive. As African economies continue to grow, population in these marginal areas may level out or decline due to migration to urban centres. However, currently, population growth is considered the major driver of change and potential degradation.

Legal frameworks to stabilize and sustain FBFSs are either not in place or not enforced. Farmers have insufficient legal protection to make safe, long-term investments such as planting timber. While urban centres should provide growing markets for products, FBFS farmers produce the same food crops as farmers in other systems which have undergone intensification, are more competitive and are closer to urban centres. The few highly appreciated products that are largely from hunting, fishing and gathering and would fetch high prices in urban markets, pose a high risk of loss because they are highly perishable. FBFS dwellers have a clear competitive advantage in collecting or producing such specialty products, yet need the infrastructure to get them to market. If market access was improved, FBFS dwellers may change land and forest use from a currently dominantly exploitative to a more conserving and protecting approach.

A transition to tree crop systems appears the most likely scenario in which livelihoods may be maintained and potentially improved without compromising ecosystem functioning. This depends on the type of tree crop: oil palm plantations are ecologically poor systems, and cocoa under natural shade retains many trees and thus ecological niches for other life forms. To provide incentives to retain or plant trees, farmers require tenure rights to trees on their land, necessitating changes in forestry and land tenure laws

and specific agroforestry policies. Ideally, farmers would receive money from governments for avoiding deforestation and forest degradation (REDD+) and for keeping a permanent carbon stock on their farms (PES: payment for environmental services for smallholder carbon projects). Currently, administering these schemes is too complex, even for developed institutions of the Organisation for Economic Co-operation and Development (OECD).

A full implementation of REDD+ would create the following scenario: shifting cultivation and some fallow / crop rotation systems will gradually disappear with no more felling, slashing and burning, but rather permanent fields, requiring no new clearings in the forest. Fallows will instead be managed with saplings and planted trees. Trees will be abundant in landscapes and around homesteads. Cocoa and coffee agroforests and smallholder rubber and oil palm should be promoted. These last two tree crops need industrial plants for processing of raw rubber and palm bunches, but this could be installed at the village level. Such developments are evident in South East Asia (Malaysia, Indonesia). REDD+ financing and PES could accelerate this evolution. It will also require more agroforestry and agrisilvicultural research in central Africa to identify the most suitable trees and systems.

Under this scenario, rural areas will be attractive for young people to settle as agroentrepreneurs. Systems could also include intensified poultry, pig production and aquaculture (tilapia, clarias), integrated with crop production, using byproducts from agriculture. Biogas from crop residues and manure can substitute firewood and charcoal. Compost from biogas production will be recycled as organic manure. Rural electrification could be promoted, using locally grown bio-fuels such as palm oil or *Jatropha curcas* oil, further reducing the need for wood-based energy. The landscape will become more complex with different plant and animal species, enhancing biodiversity, as less land is cleared for crops.

However, for the FBFS in Africa to create pathways out of poverty, profound policy and strategic shifts are required and would rely on the Maputo commitment of spending at least 10 per cent of national budgets on agriculture being honoured. Under such a scenario, more food self-reliance and less dependency on imports would be central. An improved investment climate for agriculture as well as more focus on rural areas and their populations and probably increased protection against imports are required.

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References

- Agrawal, A., Cashore, B., Hardin, R., Shepherd, G. and Benson, C. (2013) *Economic contributions of forests*. Background paper prepared for the United Nations Forum on Forests. Tenth session, 8–19 April 2013, Istanbul.
- Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R. and Yanda, P. (2007) 'Africa. Climate change 2007: impacts, adaptation and vulnerability'. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds) *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, pp. 433–467.

- Brautigam, D. (2010) China and the African land grab: the DRC oil palm deal, www.chinaafrica-realistory.com/2010/03/china-and-african-land-grab-drc-oil.html.
- Broughton, A. (2013) 'Land grabbing: a new colonialism', *Green Social Thought: A Magazine of Synthesis and Regeneration*, vol. 6, pp. 25–29.
- Büttner, U. and Hauser, S. (2003) 'Farmers' nutrient management practices in indigenous cropping systems in southern Cameroon', *Agriculture, Ecosystems and Environment*, vol. 100, pp. 103–110.
- Carrière, S.M., Letourmy, P. and McKey, D.B. (2002) 'Effects of remnant trees in fallows on diversity and structure of forest regrowth in a slash-and-burn agricultural system in southern Cameroon', *Journal of Tropical Ecology*, vol. 18, pp. 375–396.
- CIFOR (2012) 'Counting on the environment: the contribution of forests to rural livelihoods', *Conference report of the Poverty Environment Network (PEN)*, www.cifor.org/pen/news-and-events/london-conference.html.
- Coomes, O.T., Takasaki, B. and Rhemtulla, J.M. (2011) 'Land-use poverty traps identified in shifting cultivation systems shape long-term tropical forest cover', *Proceedings of the National Academy of Sciences*, vol. 108, no. 34, pp. 13925–13930.
- Degrande, A. and Duguma, B. (2000) *Adoption potential of rotational hedgerow intercropping in the humid lowlands of Cameroon*. Agricultural Research & Extension Network paper 103. Overseas Development Institute, London.
- Diaw, M.C. (1997) *Si, Nda Bot et Ayong: culture itinérante, occupation des sols et droits fonciers au Sud-Cameroun*. Réseau foresterie pour le développement rural 21e. ODI.
- Dixon, J., Gulliver, A. and Gibbon, D. (2001) *Farming systems and poverty: improving farmers' livelihoods in a changing world*. FAO.
- FAOSTAT (various years) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- Gockowski, J., Tonye, J., Baker, D., Legg, C., Weise, S., Ndoumbé, M., Tiki-Manga, T. and Fouaguégué, A. (2004) *Characterization and diagnosis of farming systems in the forest margins benchmark of Southern Cameroon*. IITA Social Sciences Working Paper No 1. Ibadan, Nigeria.
- Green, N., Sovacool, B.K. and Hancock, K. (2015) 'Grand designs: assessing the African energy security implications of the grand Inga dam', *African Studies Review*, vol. 58, pp. 133–158.
- Guillemin, R. (1956) 'Evolution de l'agriculture autochtone dans les savanes de l'Oubangui', *Agronomie Tropicale*, vol. 11, pp. 143–176.
- Hauser, S. (2007) 'Plantain (*Musa* spp. AAB) bunch yield and root health response to combinations of mechanical, thermal and chemical nematode control measures on suckers', *African Plant Protection*, vol. 13, pp. 1–15.
- Hauser, S., Bengono, B. and Bitomo, O.E. (2008a) 'Short- and long-term maize yield response to *Mucuna pruriens* and *Pueraria phaseoloides* relay fallow and biomass burning versus mulching in the forest zone of southern Cameroon', *Biological Agriculture and Horticulture*, vol. 26, pp. 1–17.
- Hauser, S., Mekoa, C. and Jacobsen, K. (2008b) 'Bunch yield response of two cultivars of plantain (*Musa* spp., AAB, subgroups French and False horn) to hot-water treatment and fertilizer application planted after forest and bush / grass fallow', *Archives of Agronomy and Soil Science*, vol. 54, pp. 541–556.
- Hauser, S. and Nolte, C. (2002) 'Biomass production and N fixation of five *Mucuna pruriens* varieties and their effect on maize yields in the forest zone of Cameroon', *Journal of Plant Nutrition and Soil Science*, vol. 165, pp. 101–109.
- Hauser, S., Nolte, C. and Carsky, R.J. (2006) What role can planted fallows play in humid and sub-humid West Africa? *Nutrient Cycling in Agroecosystems*, vol. 76, pp. 297–318.
- Hauser, S. and Norgrove, L. (2013) 'Slash-and-burn agriculture, effects of', in Levin S.A. (ed.) *Encyclopedia of Biodiversity*, second edition, vol. 6. Academic Press, pp. 551–562.
- Ickowitz, A. (2011) 'Shifting cultivation and forest pressure in Cameroon', *Agricultural Economics*, vol. 42, no. 2, pp. 207–220.
- IITA (2017) *CGIAR Research Program (CRP) 1.2. Humidtropics: Integrated Systems for the Humid Tropics*. <https://humidtropics.cgiar.org/>.
- Index Mundi (2015) *Congo, The Democratic Republic Of. The Palm Oil Production by Year*. www.indexmundi.com/agriculture/?country=cd&commodity=palm-oil&graph=production.

- Jori, F. and Chardonnet, P. (2001) 'Cane rat farming in Gabon: status and perspective', in Ebedes, H., Reilly, B., van Hoven, W. and Penzhorn, B. (eds) *Sustainable utilization—conservation in practice. Proceedings of the 5th International Wildlife Ranching Symposium*, Pretoria, South Africa
- Kleinschroth, F., Gourlet-Fleury, S., Sist, P., Mortier, F. and Healey, J.R. (2015) Legacy of logging roads in the Congo Basin: How persistent are the scars in forest cover? *Ecosphere*, vol. 6, no. 4, art. 64.
- Laporte, N., Stabach, J., Grosch, R., Lin, T. and Goetz, S. (2007) 'Expansion of industrial logging in Central Africa', *Science*, vol. 316, p. 1451.
- Laudelout, H. (1990) *La jachère forestière sous les tropiques humides*. Unité des Eaux et Forêts, Centre de Recherches Forestières de Chimay. Université Catholique de Louvain.
- Leather, C. (2009) 'Bridging the divide: the reform of global food security governance', *Oxfam Policy and Practice: Agriculture, Food and Land*, vol. 9, no. 6, pp. 68–81.
- Lescuyer, G., Cerutti, P.O., Mendoula, E.E., Eba'a Atyi, R. and Nasi, R. (2010) 'Chainsaw milling in the Congo Basin', in Wit, M. and van Dam, J. (eds) *Chainsaw milling: supplier to local markets*. Tropenbos International, Wageningen.
- Mabika, C.M. and Shapiro, D. (2012) 'School enrollment in the Democratic Republic of the Congo: family economic well-being, gender, and place of residence', *African Population Studies*, vol. 26, no. 2, pp. 197–220.
- Mayaux, P., Bartholomé, E., Fritz, S. and Belward, A. (2004) 'A new land-cover map of Africa for the year 2000', *Journal of Biogeography*, vol. 31, pp. 861–877.
- Mayaux, P., Pekel, J.F., Desclée, B., Donnay, F., Lupi, A., Achard, F., Clerici, M., Bodart, C., Brink, A., Nasi, R. and Belward, A. (2013) 'State and evolution of the African rainforests between 1990 and 2010', *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 368, no. 1625, 20120300.
- Ministère de la Planification et de la Programmation du Développement (2005) Enquête Gabonaise pour le suivi et l'évaluation de la pauvreté (EGEP 2005), Rapport sur les indicateurs de base du bien-être, Libreville. www.oecd.org/fr/cad/efficacite/Gabon%205.pdf.
- Mrunal (2012) [Climate Change] Kyoto Protocol, Carbon Trading, Copenhagen Accord: Meaning, Explained. <http://mrunal.org/2012/09/enb-kyoto.html>.
- Nielsen, M.R., Pouliot, M. and Kim Bakkegaard, R. (2012) 'Combining income and assets measures to include the transitory nature of poverty in assessments of forest dependence: evidence from the Democratic Republic of Congo', *Ecological Economics*, vol. 78, pp. 37–46.
- Nin-Pratt, A., Johnson, M., Magalhaes, E., You, L., Diao, X. and Chamberlin, J. (2011) *Yield gaps and potential agricultural growth in West and Central Africa*. International Food Policy Research Institute.
- Nolte, C., Ondo Zo'o, B. and Dondjang, J.P. (2007) 'Farmer's perception of planted calliandra tree fallows for shortening fallow cycles in southern Cameroon', in Bationo, A., Waswa, B., Kihara, J. and Kimetu, J. (eds) *Advances in integrated soil fertility management in sub-Saharan Africa: challenges and opportunities*. Springer.
- Norgrove, L. (2003) Agrisilviculture systems: timber–food crop systems in the humid tropics', *Paideusis*, vol. 3, pp. 1–15.
- Norgrove, L. and Hauser, S. (2002) 'Measured growth and tree biomass estimates of *Terminalia ivorensis* in the 3 years after thinning to different stand densities in an agrisilvicultural system in southern Cameroon', *Forest Ecology and Management*, vol. 166, pp. 261–270.
- Norgrove, L. and Hauser, S. (2014) 'Improving plantain (*Musa* spp. AAB) yields on smallholder farms in West and Central Africa', *Food Security*, vol. 6, no. 4, pp. 501–514.
- Norgrove, L. and Hauser, S. (2015) Estimating the consequences of fire exclusion for food crop production, soil fertility and fallow recovery in shifting cultivation landscapes in the humid tropics. *Environmental Management*, vol. 55, no. 3, pp. 536–549.
- Norgrove, L., Hauser, S. and Bassanaga, S. (2002) 'Effects of fertilizer regime and type of shade treatment upon growth of *Ricinodendron heudelotii* saplings in a mixed species tree crop system', in Hera, C., Schnug, E., Topbas, T.M., Gunal, H. and Ersahin, S. (eds) *Proceedings, 13th International Fertilizer Symposium. Fertilizers in Context with Resource Management in Agriculture*, Tokat Turkey, pp. 515–521. International Scientific Centre of Fertilizers, Bucharest.

- Ogbe, F.O. Dixon, A.G.O., Hughes, J.A., Alabi, F. and Okechukwu, R.U. (2005) *The status of cassava mosaic disease, cassava begomo-viruses and whitefly vector populations in Nigeria*. International Institute of Tropical Agriculture, Ibadan.
- Oxfam (2011) Blogs, www.oxfamblogs.org/eastafrica/wp-content/uploads/2010/11/Land-Grabbing-in-Africa-Final.pdf.
- République du Cameroun (2003) *Document de stratégie de réduction de la pauvreté*, www.researchictafrica.net/countries/cameroon/Poverty_Reduction_Strategy.pdf.
- Robiglio, V., Lescuyer, G. and Cerutti, P.O. (2013) 'From farmers to loggers: the role of shifting cultivation landscapes in timber production in Cameroon', *Small-scale Forestry*, vol. 12, no. 1, pp. 67–85.
- Robiglio, V., Minang, P.A. and Asare, R. (2011) *On-farm timber production for emission reduction with sustainable benefits at the tropical forest margins*. ASB Policy Brief No. 23. ASB Partnership for the Tropical Forest Margins, Nairobi.
- Robiglio, V., Ngendakumana, S., Gockowski, J., Yemefack, M., Tchienkoua, M., Tchawa, P., Tchoundjeu, Z. and Bolognesi, M. (2010) *Reducing emissions from all land uses in Cameroon*. Final National Report. ASB Partnership for the Tropical Forest Margins, Nairobi.
- Rulli, M.C., Saviori, A. and D'Odorico, P. (2013) 'Global land and water grabbing', *Proceedings of the National Academy of Sciences*, vol. 110, no. 3, pp. 892–897.
- Russell, D. (1993) *Resource management strategies in the central African forest zone: a handbook for IITA's humid forest station*. Mimeograph. Humid Forest Station, IITA.
- Russell, D., Mbile, P. and Tchamou, N. (2011) 'Farm and forest in Central Africa: toward an integrated rural development strategy', *Journal of Sustainable Forestry*, vol. 30, nos. 1–2, pp. 111–132.
- Siebert, S., Portmann, F.T. and Döll, P. (2010) 'Global patterns of cropland use intensity', *Remote Sensing*, vol. 2, pp. 1625–1643.
- Snapp, S.S., Rohrbach, D.D., Simtowe, F. and Freeman, H.A. (2002) 'Sustainable soil management options for Malawi: can smallholder farmers grow more legumes?' *Agriculture, Ecosystems and Environment*, vol. 91, pp. 159–174.
- Sonneveld, B. and Dent, D.L. (2009) 'How good is GLASOD?' *Journal of Environmental Management*, vol. 90, no. 1, pp. 274–283.
- Tueche, R., Norgrove, L., Hauser, S. and Cadisch, G. (2013) 'Tillage and varietal impacts on tomato (*Solanum lycopersicum* L.) production on an Ultisol in central Cameroon', *Soil and Tillage Research*, vol. 128, pp. 1–8.
- United Nations (1997) *United Nations Conference on Environment and Development (UNCED)*, www.un.org/geninfo/bp/enviro.html.
- Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M. and van Asten, P. (2014) 'Sustainable intensification and the African smallholder farmer', *Current Opinion in Environmental Sustainability*, vol. 8, pp. 15–22.
- von Braun, J. and Meinzen-Dick, R. (2009) *Land grabbing by foreign investors in developing countries: Risks and opportunities*. Policy Brief 13. International Food Policy Research Institute, www.ifpri.org/sites/default/files/publications/bp013all.pdf.
- Waha, K., Müller, C., Bondeau, A., Dietrich, J.P., Kurukulasuriya, P., Heinke, J. and Lotze-Campen, H. (2013) 'Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa', *Global Environmental Change*, vol. 23, no. 1, pp. 130–143.
- Washington, R., James, R., Pearce, H., Pokam, W.M. and Moufouma-Okia, W. (2013) Congo Basin rainfall climatology: can we believe the climate models? *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 368, no. 1625, 20120296.

13 Large-scale irrigated farming system

The potential and challenges to improve food security, livelihoods and ecosystem management

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Key messages

- The large-scale irrigated farming system (LSIFS) constitutes a complementary addition to other irrigation systems found in Africa. They can be sustainably expanded, particularly in sub-Saharan Africa, to contribute to the attainment of SDGs on ending poverty and hunger and enhancing resilience of production and livelihoods to climate change and other shocks.
- Sustainable expansion that would enable the full social and livelihood benefits of LSIFS to be realized by all gender groups cannot be pursued on a business as usual basis. Lessons learned from sixty years of failures and successes of large-scale irrigation schemes in Africa must be utilized to develop efficient, equitable and ecologically benign LSIFS.
- Strategic priorities to establish well-performing, livelihood-enhancing and environmentally friendly LSIFS include improved water management, distribution and drainage, increased use of renewable energy sources for irrigation and agroprocessing, improved access of women and youth farmers to irrigated land, improved access of all smallholder farmers to finance, irrigation advisory services, input and output markets, empowerment of water users' associations and public-private partnerships to increase investment and improve management of LSIFS.
- Households in well-managed and sustainable LSIFS will be able to escape poverty and improve their well-being through intensification and diversification of agricultural production activities and off-farm income earned from agroprocessing and other employment opportunities created through the spillover effects of irrigation.

Summary

The potential of irrigation to improve food security, reduce poverty and promote agricultural growth is widely recognized by governments across Africa. Yet, despite availability of abundant but underutilized water resources, expansion of irrigation has been slow, especially in sub-Saharan Africa (SSA). This chapter reviews the constraints, opportunities and strategic priorities for sustainable development of the large-scale irrigated farming system (LSIFS) in Africa, with an emphasis on SSA. It begins by examining the array of

biophysical, technical, human capital, policy and institutional factors that have shaped the evolution of LSIFS, followed by an assessment of the performance of the system. The assessment indicates that based on productivity, sustainability and human development outcomes, performance of LSIFS has improved over time. But much remains to be done in the area of irrigation water management and distribution, development of new irrigation and business management models, empowerment of farm households and local institutions, and agroecosystem management. Intensification and diversification of agricultural production through irrigation, better water management and improved access to finance and markets, remain the most important pathways out of poverty for households in this farming system. The chapter concludes by discussing the strategic priorities that can be pursued to turn potential into reality and make LSIFS a bridge to improved food security, poverty reduction and agricultural growth in Africa without harming the environment.

Introduction

Irrigation holds great potential for agricultural growth, food security and poverty alleviation in Africa, but its contribution to date has been constrained by a lack of investment to expand the area under irrigation and the poor performance of existing public sector managed large-scale irrigation schemes. In 2013, nearly 243.1 million ha of land was cultivated in SSA. However, the total area equipped for irrigation was 8.2 million ha – only 3.4 per cent of the cultivated area and less than one-fifth of the 39 million ha deemed suitable for irrigation (FAO 2011, 2016a, 2016b). In contrast, irrigation plays an important role in north Africa, where it accounts for 23 per cent of cultivated area. Against this backdrop, the need for investment to develop and use the abundant land and water resources has never been greater.

Investment in economically viable, environmentally sustainable and socially acceptable large-scale irrigation systems can increase agricultural productivity and incomes and lower food prices. Such irrigation systems can also contribute indirectly through increased rural and urban employment arising from the multiplier effects of growth in the rural and urban non-farm economy (Lipton et al. 2003; Namara et al. 2010; Saleth et al. 2003) and by permitting other livelihood activities such as livestock keeping, fish production and small and medium enterprises (e.g. brick making). Case studies of rehabilitated and new large-scale irrigation schemes indicate that these benefits of irrigation are achievable under the right economic, social and institutional environment (Aw and Diemer 2005; IDA 2007).

Overview of the irrigated farming system and subsystems

The large-scale irrigated farming system often co-exists in the same country with medium-, small- and micro-scale irrigated systems (Table 13.1). These systems differ in terms of management (public or private), the primary source of water (surface or groundwater), costs of maintenance and operation, and the implications they hold for food security, livelihoods and the environment.

The focus of this chapter is on the large-scale irrigated farming system (LSIFS). This is usually centred around a public sector irrigation scheme distributing water collected in dams from nearby rivers, over a command area, i.e. area that can be physically irrigated and is fit for cultivation, spreading over thousands of hectares (Figure 13.1). Land is leased out to farmers who cultivate mandated crops (e.g. cotton or rice) in addition to a variety of other crops (Box 13.1).

Figure 13.1 Markala dam, large-scale irrigation infrastructure, Office du Niger, Mali.

Source: Regassa Namara.

Table 13.1 A typology of irrigated farming subsystems in sub-Saharan Africa based on management and command area

<i>Subsystem</i>	<i>Description</i>	<i>Typical command area (ha)</i>
Large-scale	Public and / or commercial irrigation systems, growing cash crops for export and staple food crops for domestic and regional markets	$\geq 1,000$
Medium-scale	Community and/or agribusiness managed systems growing staples, fruits and vegetables for domestic, regional and export markets	≥ 100 to $\leq 1,000$
Small-scale	Community and/or farmer managed systems producing food and horticulture crops for domestic market	≥ 1 to ≤ 100
Micro-scale	Farmer managed systems producing staple foods and horticulture crops for urban and peri-urban centres	≤ 1

Box 13.1 A typical household in large-scale irrigated farming system

A typical household in an LSIFS has a family of seven to eight persons, comprising four or five adults and three children. Depending on the size of the irrigation scheme that is at the heart of the farming system, the family owns 4–8 ha of irrigated land and about 1–2 ha of rainfed land outside the scheme. The family cultivates at least one cash crop (cotton or rice) on the irrigated land in rotation with other crops grown for subsistence (sorghum, wheat, etc.), soil fertility maintenance and fodder (groundnuts or a leguminous forage). Millet and/or sorghum is typically grown on the rainfed land. The family owns about 9–10 TLU (tropical live-stock unit). One or two adult household members work outside the farm in nearby towns, requiring the family to rely on hired labour for about 40–50 per cent of the farm work on the irrigated fields. Average crop yields are about 3 t/ha for paddy rice, 1.4 t/ha for cotton seed, 2 t/ha for sorghum, 1.4 t/ha for wheat and 1.9 t/ha for groundnuts. Average crop yields in all cases are well below the potential achievable due to a shortage of irrigation water, inadequate application of fertilizers and pesticides, and limitations due to soil and crop-specific factors. Approximately 80 per cent of total household income comes from crop production, including the portion retained for household consumption; 5 per cent from sales of livestock and livestock products; and 15 per cent from off-farm business. A typical household in this system is able to meet the minimum cereal requirement of 214 kg per capita after paying for production costs.

Sources: Guvele (2001); Mather and Kelly (2012); World Bank (2000).

As shown in Figure 13.2, the large-scale irrigated farming system is found in Egypt, Sudan, Mali, Nigeria and Somalia. There are significant additional unmapped areas of irrigation in Morocco and other countries. The areas surrounding these LSIFS also support other livelihoods such as livestock rearing and fishing. The map, however, does not show the myriad small-scale irrigation systems that are embedded in some of the other farming systems covered in this book.

Table 13.2 provides basic data on the LSIFS. The system covers approximately 46 million ha and supports a total human population of 124 million, of which 86 million are located along the Nile Delta and River in Egypt. About 48 million in the LSIFS are directly involved in agricultural production. Despite the farming system's potential, almost 58 per cent of the rural population lives in extreme poverty. The farming system has relatively good market access compared to the other farming systems, but access to services – extension, credit, insurance, etc. – varies from low to medium.

North Africa contains approximately 5 million ha of LSIFS, concentrated in Egypt and Sudan and, to a lesser extent, Morocco. The Nile Valley schemes have dominated Egyptian farming for thousands of years. In contrast, although the Gezira Scheme in Sudan (Box 13.2) is famous, rainfed cropping and pastoralism dominate the Sudanese agricultural sector.

Figure 13.2 Distribution of large-scale irrigated farming system in Africa.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Table 13.2 Basic system data (2015): large-scale irrigated farming system

Item	Data
Total human population (million)	124
Agricultural population (million)	48
Total area (million ha)	46
Cultivated area (million ha; % of total area)	11.7; 25
Irrigated area (million ha; % of cultivated area)	8.0; 69
Total livestock population (million TLU)	23
Major agroecological zone	Tropical warm arid
Length of growing period (average, days; core range, days)	47; 0–90

(continued)

Table 13.2 (continued)

<i>Item</i>	<i>Data</i>
Access to services (low/medium/high)	Low to medium
Distance to 50k market (average, hr; core range, hr)	3.8; 0–4
Agricultural population density (persons/total area; persons/cultivated area)	1; 4.1
Livestock density (TLU/total area; TLU/cultivated area)	0.49; 1.9
Standard farm and herd size (cultivated area/household; TLU/household)	1.3; 2.6
Extreme poverty (% of rural population)	58*

Source: Refer to Table 2.4.

*For sub-Saharan Africa only.

Box 13.2 Challenges and emerging opportunities in the Gezira LSIFS

The Gezira irrigation scheme in Sudan was formally established in 1925 by the colonial authorities with the aim of growing cotton as a cash crop over a command area of approximately 126,000 ha. Since then the scheme has grown in size and complexity. It currently encompasses a command area of 924,000 ha that is leased out to about 130,000 tenant farmers. The population of farmers and their families is about 1 million. There are also about 150,000 seasonal labourers who together with their families add another 1 million to the population of the farming system. Another 1 million people supply goods and services, meaning that approximately 3 million people rely on the scheme and associated farming system for their livelihoods.

Some of the initial challenges that tenant farmers faced included top-down management and administration of irrigation water, restrictions on crops that could be cultivated, and low agricultural yields which in turn led to low incomes. To address these and other challenges, the government passed a new Gezira Scheme Act in 2005, which among other things allowed: freedom of crop choice; farmers' right to dispose of their freehold or leasehold land through sale, mortgage or assignment; the establishment of water users' associations (WUAs); and the participation of the private sector in the provision of commercial services to farmers. However, these reform measures have not resulted in marked improvements in agricultural productivity. WUAs lacked the capacity and know-how to actively play a role in the management of irrigation operations at the field canal level. Also, despite the freedom of crop choice, farmers until recently struggled to find a suitable alternative crop to replace cotton as a cash crop.

In 2010, the Japan International Cooperation Agency (JICA) introduced rice into the farming system on a trial basis. Although rice is a latecomer to the farming system, it is already being hailed as a portent of better times, because with good yields, it has allowed farmers to almost triple their incomes.

Sources: CFI 2013; World Bank 2010a.

Trends and drivers of change across the large-scale irrigated farming system

Population, hunger and poverty

Over the period 2000–2010, human population in the LSIFS in SSA increased from about 25 million to approximately 32 million people, representing an average annual compound growth rate of 3.2 per cent. Increasing population pressure and low agricultural productivity have led to the persistence of hunger and poverty in SSA and made food security a key priority for many African governments. These pressures have also brought about a change in the orientation of LSIFS in many SSA countries – from systems designed to produce cotton fibre for export, to systems focusing on staple food production in an attempt to ensure food self-sufficiency. However, due to poor irrigation water management, inadequate extension services support and government control of input and output prices, aggregate agricultural output and farmers' incomes remained low until price and institutional reforms were introduced in the 1990s.

The increase in population has also led to increased fragmentation of land on many LSIFS. Families who were originally allocated about 8 ha of land in the Office du Niger irrigation zone in Mali have had to subdivide the land among their children. At the same time, there is increased demand for irrigated land by farmers already in the scheme and those willing to join (Mather and Kelly 2012).

Also, diets are changing as a result of urbanization and income growth. There is increased demand for horticulture products – vegetables, fruits and spices. This growth in demand, both domestically and externally, is promoting horticulture production on medium- to large-scale irrigated farming systems in a number of African countries including Egypt, Morocco, Ghana, Ethiopia, Kenya, Nigeria and Zambia.

Furthermore, the growing phenomenon of rural-urban migration appears to be drawing family labour away from LSIFS (Box 13.2) across Africa in the same way as it affects other non-urban farming systems.

Natural resources and climate

In SSA, agricultural water resources are relatively abundant but underutilized due to inadequate water storage and irrigation infrastructure. FAO (2011) estimates that average agricultural water withdrawals are 1.3 per cent of renewable water resources and ground-water use is less than 20 per cent of renewable supplies, indicating significant scope for surface water and groundwater development. Other studies, for example Pavelic et al. (2012) and MacDonald et al. (2012), have shown evidence which indicates that groundwater is the largest and mostly widely distributed store of freshwater in Africa.

With expansion of irrigated area and new land investments growing apace within the perimeters of some of the irrigation schemes that support LSIFS, water availability may soon become a problem. Analysis of this situation in the Office du Niger (Sidibé and Williams 2016) suggests that if the current water management system based on a flat rate per hectare pricing is maintained, aggregate water demand for irrigation may exceed the average annual water availability in Markala dam, with negative consequences for environmental flows and the possibility of conflicts among different water users.

Increasing climate variability and climate change pose both a challenge and an opportunity for LSIFS. According to some predictions, greater variability in precipitation

will significantly affect surface water across a quarter of the continent (De Wit and Stankiewicz 2006), implying a possible reduction in water availability for irrigation. But the possibility of more frequent extreme weather events such as floods and droughts, suggests that water storage and irrigation may provide an opportunity for capturing and utilizing flood water that would otherwise have been lost, to mitigate the effects of drought and improve agricultural production.

Energy

In some LSIFS, energy is needed to pump water into canals to irrigate planted fields. Rising fuel, electricity and pump maintenance costs since the late 2000s have disrupted water supply to farmers on such LSIFSs. For instance, in Ghana, the inability of several large-scale irrigation schemes to pay their electricity bills has led to the shutdown of water pumping operations and supply of irrigation water to farmers, leading to a loss of household income. The option of using solar and wind power to lift water is being explored in many countries and has progressed much more rapidly in small-scale irrigation systems compared with LSIFS. A private sector company in Ghana, Integrated Water and Agricultural Development Ghana Limited (IWAD), which has established a large-scale irrigation scheme involving neighbouring farmers, has installed a 0.5 megawatt solar power plant with a mini grid to supply renewable energy for irrigation on both the nucleus and nearby smallholder farms and other agro-processing applications (<http://cms.iwadghana.com/>).

Human and social capital

On many LSIFS during the 1960s to 1990s, water resource administration and irrigation management were handled by government employees who were mostly engineers. These professionals lacked training in the broader environmental and socioeconomic issues that are essential to making irrigation beneficial to farmers. Apart from limited capacity, frequent funding cuts and political interference curtailed the ability of available staff to perform necessary operation and maintenance activities, collect relevant hydrological, meteorological, water supply and distribution data, and provide adequate irrigated farming support services to farmers. These shortcomings contributed to the failure of many large-scale public irrigation projects during this period, as they were caught in a vicious cycle of infrastructure disrepair and poor performance which also impacted negatively on farm households. But the failure has also spurred capacity strengthening in many irrigation management agencies, for example in Kenya and Tanzania.

From the 1960s to the 1990s, land allocation in many LSIFS failed to incorporate gender considerations and this exacerbated existing imbalances in resource allocation for women. For instance, land allocation often favoured male household heads, thus cutting women out of irrigated land ownership except as labourers for the household heads (van Koppen 1998). Although gender-based farming practices where men and women cultivate separate fields are common in many parts of SSA, this reality was often ignored, resulting in gender inequity in access to land and water resources (IFAD 2007).

However, in recent years, these omissions have gradually been corrected with impetus for change coming from national strategic initiatives such as the Poverty Reduction Strategy Programmes (PRSPs). These programmes, which emphasize the link between poverty and gender, together with the gender strategies of donor agencies, are increasingly promoting women's empowerment as a means of reducing poverty and food insecurity. With this

new perspective and lessons learned from failed irrigation projects, issues of gender equity and poverty alleviation are now being addressed through capacity building and securing of greater access rights and control over resources for women and poor vulnerable people. But efforts to ensure that women have access to land in LSIFS or are members of WUAs and their management committees have not entirely succeeded. Local norms regarding gender and other elements of social stratification still prevent women and marginalized groups from having full control over land and full decision-making powers over resources. Due to poor access to finance, women still experience serious problems in mobilizing sufficient labour to make the most of the potential benefits that irrigation offers.

Science and technology

Plant breeding and agronomic research have contributed to increased crop yields in LSIFS. High-yielding germplasms coupled with inputs such as fertilizers, pesticides and herbicides, and improved water availability at the field level have raised yields of rice, cotton, wheat and sorghum (Figure 13.3).

In addition, market reforms launched as part of the structural adjustment programmes in the late 1980s and early 1990s in many SSA countries initially provided incentives to farmers. For instance, in Mali, such reforms, including the abolition of the monopoly

Figure 13.3 Irrigated rice farming, Karfiguela irrigation scheme, Burkina Faso.

Source: Regassa Namara.

on rice milling and marketing by the Office du Niger (the government management agency), allowed rich farmers and entrepreneurs to introduce simple technologies (small threshers and dehullers) for post-harvest processing of rice in rural areas close to the farms. This encouraged farmers in the Office du Niger to increase rice production as they no longer had to travel long distances and incur huge transport costs to mill their rice. The machines also reduced the workload of women by saving them the tedium and long hours of pounding paddy for the family meal. Entrepreneurs sensing a new business opportunity and the need to reduce the percentage of broken grains produced by the simple threshers and dehullers, subsequently introduced relatively more sophisticated rice-milling technologies, thereby spawning an off-farm small and medium enterprise industry in the rural areas (Barry et al. 2009).

Research studies have shown that satellite images, remote sensing and earth observation decision-support tools can be used to analyse the performance of LSIFS and support the development of performance-enhancing solutions that can improve irrigation water management and ultimately benefit farmers (Borgia et al. 2012; Hamid et al. 2011). These new tools increase access and capacity to collect data in a systematic, detailed and comprehensive manner on a vast array of variables, including water storage and distribution patterns, evapotranspiration, crop yields, droughts and flooding. They also allow monitoring of environmental factors in near real time.

Trade and markets

Profound changes in domestic, regional and international markets are creating new opportunities for production and trade in horticulture commodities. These changes, driven by rising incomes, faster urbanization and technological advances are increasing demand for high-value horticulture products such as fruits, vegetables and spices. There is evidence that high-value markets catering for domestic consumption are the fastest growing in many SSA countries. Neven and Reardon (2004) reported that from the mid-1990s, supermarkets in Kenya grew at 18 per cent annually and reached one-fifth of the overall food market in cities by 2002. In South Africa, supermarkets held 55 per cent of the national food retail market in the early 2000s. Williams (2011) estimated that Africa's export of horticultural products grew at an average annual rate of 10.7 per cent between 1990 and 2008, double the average annual growth rate of traditional African agricultural exports during the same period. This growth in markets for horticultural products is promoting a range of small- to large-scale irrigated horticulture systems across Africa. In the LSIFS of Office du Niger where rice production predominates, mango, onions and potatoes are providing a second out-of-season cash crop for farmers. With technical assistance from foreign companies and donors, farmers in this LSIFS have started to access export markets.

Policies and institutions

Since the mid-1990s, many governments in Africa have initiated market reforms initially focused on market-oriented liberalization to 'get prices right' and later on 'getting institutions right', including introduction of participatory approaches to irrigation management and devolution of irrigation management to WUAs. In recent years, there has been increased interest in the question of how to make markets work more effectively for the poor. Many PSRPs and associated economic development strategies and policies

have placed high priority on stimulating increased market participation by poor farmers through improving their access to markets and involving them in viable value chains.

These initiatives have created opportunities for farmers in LSIFS. Freedom of crop choice, removal of price controls and liberalization of produce marketing have allowed farmers to diversify and grow a range of new crops which they are now directly marketing. Reform of the previous top-down approach in design, operation, implementation and maintenance of large-scale public irrigation schemes has permitted farmers to form WUAs, which has given them a voice in water and irrigation operations management (Table 13.3). In addition, many governments in Africa have invested in land reforms to give greater tenure security to farmers (see Aw and Diemer 2005 for the case of Mali; and Gezira Scheme Act 2005 for Sudan). In some cases, within these reforms, there has been an emphasis on improving the rights of women to own land. As a result of these institutional and market reforms, there is emerging evidence in a number of countries that previously underperforming large-scale public irrigation schemes (e.g. Office du Niger in Mali) are becoming financially sustainable and highly productive irrigation systems with concomitant benefits to farmers (Aw and Diemer 2005; Barry et al. 2009).

Although government and donor investments in large-scale irrigation schemes declined sharply from the 1990s to the mid-2000s due to poor cost-benefit returns and rising concerns about the environmental and equity impact of large dams, currently there is renewed interest in large-scale irrigation schemes. This is partly driven by the recent surge in food prices and the associated risk of food insecurity to millions of vulnerable poor people. To date, the Global Agriculture and Food Security Program (GAFSP), a fund that was launched in April 2010 to support country-led efforts to fight hunger and poverty, has awarded grants totalling US\$430.5 million to eleven SSA countries to improve water management and irrigation as part of an overall agricultural and food security improvement programme.

SSA is also experiencing a new post-colonial wave of large-scale land acquisitions (LSLAs), predominantly by foreign investors, for the cultivation of biofuels, food crops and flowers. The drivers of these foreign direct investments (FDI) in agriculture are numerous and varied and have been extensively reviewed (Cotula et al. 2009; Von Braun and Meinzen-Dick 2009; World Bank 2010b; Zoomers 2010). Recipient governments have welcomed FDI and viewed it as a way of transforming their poorly performing agricultural sector through the infusion of capital, modern technology and infrastructure, including irrigation. Many of these LSLAs explicitly or implicitly include control and management of water in their contracts. The water dimensions of these LSLAs and their impacts on food security, local livelihoods of smallholder farmers and the surrounding ecosystems are only now beginning to be examined. Kizito et al. (2013) and Williams et al. (2012) found that in Ghana and Mali, LSLAs resulted in loss of access to land and associated water rights by a large number of poor farmers. This directly affected their ability to feed their families and earn income. But there are private sector firms with long-standing engagement that are leasing land from local communities for agricultural production using inclusive business models such as outgrower schemes or revenue sharing arrangements that satisfy both local demands, including increased income for farmers, and investors' interests.

Increasingly, new investments are being implemented through public-private partnership models, for example, in Ethiopia, Ghana, Nigeria and Tanzania. These are relatively new initiatives and there are several variants. In one model, the public sector invests in

and owns the irrigation infrastructure but outsources the operation and maintenance to the private sector (World Bank 2013). In another model, public land is leased out to a private sector investor who develops the irrigation infrastructure and operates, either directly or indirectly, through third party nucleus services to hundreds of emergent local farmers who are apportioned plots on the newly developed land. This is the model being piloted by AgDevCo, a private sector, social impact investment company, together with Ghana's Ministry of Food and Agriculture to develop Babator, a 4,500 ha farm in Northern and Brong-Ahafo regions for commercial rice production.

The drivers and trends in the LSFIS are summarized in Table 13.3.

System performance

Productivity

Cereals account for approximately 50 per cent of the harvested irrigated area in SSA (FAO 2005a). Across SSA (and north Africa), irrigated land represented about 3 per cent (33 per cent) of total harvested cereal land but accounted for 9 per cent (75 per cent) of total cereal production in 2006 (FAO 2011). This demonstrates the potential of irrigation to boost agricultural production and food security.

In SSA, rice is the main cereal on 25 per cent of the harvested irrigated area, with other cereals, including wheat, maize and sorghum, covering 24 per cent of the same area, but wheat and rice are the dominant irrigated staple crops in the north African countries in the Nile River Basin. Until the late 1990s, irrigated rice yields achieved by farmers on LSIFS in SSA were generally low (about 1.6 t/ha). This has been attributed to unreliable water supplies, poor water control and management, low input use, poor agronomic practices and difficulty in accessing profitable output markets (World Bank 2007).

However, emerging evidence suggests that rice on LSIFS has the potential to achieve high yield and to be competitive in local markets if farmers have good access to irrigation water, and use adequate inputs and crop management practices (Nakano et al. 2011). For instance, Table 13.4 shows paddy yield ranging from 1.3 to 4.3 t/ha, partly reflecting varying farmer access to water. It also shows that irrigated rice can offer a competitive price in local markets if water access is good (US\$299 per tonne in Doho and US\$302 per tonne in Chokwe) relative to the international price of rice (US\$275–335) in the survey year. However, prohibitive local transport costs can easily change the picture.

The variability in performance of large-scale irrigation schemes evident in Table 13.4 remains an issue across SSA. Borgia et al. (2012) analysed the variability in three large-scale irrigation schemes in Mauritania using field level observations and satellite images. They found great intra-scheme variability, with irrigation intensity varying on a scale from 0 to 1 and yield ranging from 0.4 to 7.0 t/ha in a single scheme. Analysis of the water distribution patterns within the scheme indicated that variability in irrigation water supplies and drainage were the main sources of variable yield and irrigation intensity. The evidence from this study and that of Nakano et al. (2011) suggests that finding lasting solutions to the physical, technical and organizational factors that underlie non-uniform water distribution patterns will be important in raising productivity of irrigated rice and incomes of farm households on large-scale irrigation schemes. Equally important will be access to markets for inputs and outputs, and good road infrastructure and transport systems.

Table 13.3 Evolution of the large-scale irrigated farming system (LSIFS) in response to various drivers

<i>Drivers</i>	<i>Trends</i>	<i>Implications for LSIFS structure and function</i>
Population, hunger and poverty	<ul style="list-style-type: none"> Increased population growth and incidence of hunger and poverty Rapid urbanization and changing diets Increased rural–urban migration 	<ul style="list-style-type: none"> Shift from production of cotton fibre for export to staple food crop production for domestic market Production of horticulture crops Reduction in family labour input on-farm
Natural resources and climate	<ul style="list-style-type: none"> Abundant irrigable land and water resources Increase in natural resource degradation 	<ul style="list-style-type: none"> Potential for expansion of irrigated area Reduced agricultural productivity; increased environmental externalities
Energy	<ul style="list-style-type: none"> Rising fuel (petrol and diesel) and electricity cost Introduction and increasing importance of renewable energy (solar and wind) 	<ul style="list-style-type: none"> Disruption of water pumping and supply to farmers New opportunities for water lifting and agroprocessing
Human and social capital	<ul style="list-style-type: none"> Limited human capacity in agencies managing irrigation operations Gender bias in land allocation and in membership of WUAs 	<ul style="list-style-type: none"> Poor service delivery to farmers Poor representation of women as owners and farmers of irrigated plots and in irrigation management decision-making
Science and technology	<ul style="list-style-type: none"> Improved availability of germplasm and inputs (fertilizers, herbicides, etc.) Availability of new data-gathering and decision-support tools 	<ul style="list-style-type: none"> Increased yields, but regular access of all farmers to inputs remains problematic Improved service delivery to farmers in the long run
Trade and markets	<ul style="list-style-type: none"> New opportunities for trade in high-value horticulture products in domestic and export markets 	<ul style="list-style-type: none"> Income-earning opportunities for farmers
Policies and institutions	<ul style="list-style-type: none"> Decentralized governance, including different forms of participatory irrigation management (PIM) and irrigation management transfer (IMT) to WUAs Market reforms, including abolition of price and marketing controls 	<ul style="list-style-type: none"> Mixed results in terms of irrigation water availability at field level and maintenance of irrigation infrastructure Provided incentives for farmers to diversify their production activities and market their products directly

Table 13.4 Yields and returns in large-scale rice irrigation schemes in five sub-Saharan African countries

Country, location and water availability Data	Uganda	Mozambique	Burkina Faso	Mali	Niger						
	Doho 2007	Chokwe 2007	Kou Valley	Sourou	Bagré	Niono	N'Débougou	Say2	Daibéri		
			2005–06			2005–06		2005–06			
	Facing main channel	Not facing main channel	Receive enough water	Do not receive enough water	Deteriorating access to water	Fluctuating access to water	Improved access to water	Improved access to water	Fluctuating access to water	Deteriorating access to water	
Sample size (number of households)	111	177	144	32	78	40	30	49	50	60	50
Current irrigated area (ha)	1,000	–	4,000	–	1,400	3,200	1,885	–	11,757	186	295
Mean paddy yield (t/ha)	3.2 (1.3)	2.7 (1.7)	2.2 (1.2)	1.3 (1.0)	3.2 (0.7)	3.6 (1.7)	3.2 (1.2)	3.2 (1.6)	3.1 (1.3)	4.3 (1.5)	3.6 (1.2)
Net return (US\$/ha)	671	506	143	29	564	368	166	1,000	983	438	361
Profit (US\$/ha)	377	203	35	–73	–	–	–	–	–	–	–
Unit production cost of milled rice (US\$/tonne)	299	358	302	407							
Rice grade/type	International rice price (US\$/tonne f.o.b.) in survey year										
Thai 2nd grade#			335							291	
Thai A1 grade			275							219	
Pakistan 25%			290							235	
Vietnam 50%			313							255	

Source: Nakano et al. (2011).

Note: data in parentheses are the standard deviations of mean paddy yield.

Sustainability

Economic dimension: costs and returns

The economic sustainability of LSIFS depends not only on improving the agricultural productivity but also on keeping the cost of construction and operation and maintenance of irrigation infrastructure low. Based on an irrigation project database compiled by the International Water Management Institute, Inocencio et al. (2007) showed that for a sample of 314 large- to medium-scale projects implemented in developing countries from 1965–2000, the unit total cost of new construction projects in SSA was on average twice as expensive as in non-SSA. For rehabilitation projects, the unit total cost in SSA was almost three times as high as in non-SSA. However, SSA projects that were deemed successful, because their rate of return at completion was 10 per cent or more, did not have unit costs that were significantly different from unit costs in non-SSA.

The study found that unit costs varied inversely with project size indicating a scale economy. Other key factors found to influence costs included community participation, type of irrigation infrastructure, type of crops grown and concurrent use of surface and groundwater. Projects where farmers made a large capital contribution and managed irrigation systems or shared management with a government irrigation agency recorded significantly better results in terms of keeping costs down and improving economic returns. Irrigation infrastructure designed for staple cereals showed higher unit costs and lower returns than those designed for horticulture, vegetables and fodder crops. This was partly because the heavy irrigation infrastructure such as dams, reservoirs, sluices and canals used in the irrigation of staple foods (such as rice, wheat and maize) is much more costly than the lighter infrastructure used in the cultivation of non-cereal crops. Furthermore, the declining price of cereals from the mid-1980s to mid-2000s resulted in reduced profitability relative to horticulture and vegetable crops that experienced strong demand growth. Irrigation systems that concurrently used surface and ground water performed better than those that did not.

With respect to economic returns, Inocencio et al. (2007) found that externally funded projects from the 1970s up to 1984 performed poorly due to high unit costs per hectare leading to low or negative rates of return. However, projects implemented after 1985 have fared better. A number of factors influenced performance. First is the reduction in the unit total cost of irrigation projects. Failed projects (those with rates of return below 10 per cent) had, on average, total unit costs per ha four times those of 'successful' projects (those with rates of return above 10 per cent). Second, projects where high-value crops can be produced and sold profitably do better. This is confirmed by the thriving horticultural production for export by smallholder irrigators in Kenya, Ethiopia and Zambia.

Across SSA, lessons learned from these studies are already being put to use in new irrigation projects. More recent projects are avoiding the over-sophisticated and unduly complex infrastructure of earlier projects and are often decentralized and farmer-driven, with higher farmer contribution leading to lower unit costs (Aw and Diemer 2005; IDA 2007).

Environmental dimension: salinization

Irrigation-induced salinization is a growing problem in several LSIFS resulting in extensive areas of land being taken out of productive use and threatening the productivity of other farming systems downstream. In the mid-1990s at Chokwe LSIFS in Mozambique,

salinization led to the loss of about 5,000 ha out of a total of 30,000 ha (World Bank 2007). Recent estimates in the same system are that 10,000 ha are rendered unusable due to salinization. Evidence of irrigation-induced salinization or threat of salinization has also been reported in Wonji/Shoa scheme in Ethiopia (Ruffeis et al. 2010), Office du Niger (Barry et al. 2009), Vaalharts scheme in South Africa (Verwey and Vermeulen 2011), and Chali and Bahi schemes in Tanzania (Kiunsi 2006). While the technical problems that have led to irrigation-induced salinization in each of these systems are context specific, they include one or several of the following factors: poor on-farm water management such as overirrigation and poor drainage control; poor construction, operation and maintenance of irrigation canals leading to excessive seepage; inadequate or lack of system-wide drainage infrastructure; and poor quality of construction, operation and maintenance of drainage facilities where they exist.

These technical problems, as pointed out by Umali (1993), often have their roots in other policy and institutional failures, for example inappropriate water pricing policies, poor irrigation scheduling, ineffective project planning, monitoring and evaluation, inadequate operation and maintenance budgets, inadequate extension services and farmers' lack of awareness of more efficient water management. However, salinization can also occur within irrigation systems through natural weathering of saline parent material. Barbiéro et al. (2001) and van Asten et al. (2003) provided evidence which suggests that soil salinity in irrigation schemes along the Senegal river valley was not necessarily due to secondary salinization, but rather the manifestation of salt already present in the soil before the establishment of the irrigated rice system. Whatever the cause, irrigation-related salinization imposes severe consequences not only on the farmers and households in affected production areas but also on areas and people downstream. In areas directly affected, loss of land and loss of production mean less agricultural production and income with concomitant strain on farm household food security. Drainage water discharged into rivers increases the salt load of the rivers and makes the river water less suitable for irrigation and other uses downstream.

Apart from estimates of soil salinity and land area abandoned, there is very limited empirical research on field-level and basin-wide economic and environmental impacts of irrigation-induced salinization. This gap in our knowledge will be further examined in the section on strategic priorities for the LSIFS.

Social dimension

UPSTREAM-DOWNSTREAM RELATIONSHIPS

Downstream externalities will occur through the interruption of the downstream transfer of water and sediment which would otherwise take place. This will be compounded if poor water and land management in the irrigation scheme lead to soil erosion and discharge of salt-, herbicide- and pesticide-laden drainage water downstream. Losses may be incurred by households engaged in agricultural production, fishing and firewood collection. The livelihood impacts may be substantial in semi-arid zones where downstream uses of water are critical to the economic well-being of a large number of rural households. Negative impacts on ecosystem services may also result. For instance, in northern Nigeria, construction of dams for large-scale irrigation schemes upstream of the Komadougou-Yobe river basin diverted water from Hadeija-Nguru wetlands downstream, resulting in loss of plant and animal habitat and biodiversity, and negative implications for irrigated

agricultural production in the floodplain which was dependent on water from a shallow groundwater aquifer (Barbier 2003; FAO 2005b). Dialogue and cooperation between upstream and downstream users has moderated some of the negative impacts noted earlier. But this needs to be preceded and informed by rigorous environmental impact assessment to establish the scale of the problem and to develop solutions to eliminate or mitigate the worst impacts. Understanding of local interactions and dependencies around the vicinity of large-scale irrigation infrastructure and farming systems will allow a clear linkage between upstream irrigation activities and downstream effects to be established and will facilitate the adoption of an integrated water resources management approach at a watershed level.

PUBLIC HEALTH IMPACTS

A different but related issue concerns the public health problems created by dams constructed for irrigation. In Ethiopia, the construction of small dams in Tigray region increased the spread of malaria, while the spread of urinary schistosomiasis in Burkina Faso has been associated with the increase in construction of small reservoirs (World Bank 2007). Another study reported incidences of schistosomiasis in several large-scale irrigation schemes across Africa: Morocco, Tessaout Amount; Sudan, Gezira Managil; Mali, Office du Niger; Cameroon, Lagdo; and Kenya, Mwea resulting in debilitating health consequences for farming households (Boelee and Madsen 2006).

Apart from inadequate attention to the environmental and health impacts of irrigation projects at the design stage, many of the highlighted problems are also partly attributable to weaknesses in the environmental and health regulatory and enforcement frameworks. Regular monitoring and evaluation and mitigation measures are often not implemented as funds are not budgeted for such activities.

Human development outcomes

Household income, consumption and poverty

In a farm household level study conducted in the Tigray region of Ethiopia, Gebregziabher et al. (2009) analysed the income, consumption and poverty-reduction impacts of three different types of small-scale irrigation systems (earth dams, river diversion and shallow wells). The study sampled 613 farm households (331 irrigators and 282 non-irrigators) using a three-stage stratified sampling and propensity-score matching method to compare the differences between irrigators and non-irrigators. Although the focus of the study is on small-scale irrigation systems (Figure 13.4), the findings are relevant. They found that the overall mean income gain due to participation in irrigated agriculture ranged from US\$462 to US\$520 per household per annum, which was higher than the income gain estimated for the entire sample. Poverty incidence in the irrigator's group was also significantly lower than that of non-irrigators, which was slightly higher than the regional average for Tigray and significantly higher than the national average. Total household consumption expenditure of irrigators was significantly higher than that of non-irrigators, though the difference was not as large as the difference in income between the two groups. Also, irrigators hired more labour and had lower participation in off-farm activities, reflecting the relative labour absorption potential of irrigated farming compared to rainfed farming. This was particularly so for

Figure 13.4 Small-scale irrigation, East Dangbe district, Ghana.

Source: Regassa Namara.

groundwater irrigators who also had the highest average income level among the three categories of irrigators. The results relating to groundwater irrigators are consistent with results from other developing countries (Shah et al. 2007).

Dillon (2010) assessed the impact of the scale of irrigation on household welfare in Mali, with a sample of 651 agricultural households (283 small-scale irrigators, 56 ‘large-scale’ irrigators¹ and 312 non-irrigators) in the region of Niafunke. The analysis showed significant gains in agricultural production and income for both large- and small-scale irrigators, with larger benefits accruing to the latter. Relative to non-irrigating households, small-scale irrigation had a statistically higher estimated yield of 2.1–2.4 t/ha, whereas large-scale irrigation had a point estimated yield ranging from 941 kg/ha to 1.1 t/ha. With respect to agricultural income, the effect of small-scale irrigation was generally higher, with estimates between US\$296 and US\$317. Estimates of the effects of large-scale irrigation ranged between US\$250 and US\$342 and were more variable than those of small-scale irrigation. The effects of irrigation on consumption expenditure per capita were mixed. Although there was an overall positive effect on irrigators of consumption per capita, the effects of large-scale irrigation on consumption per capita were larger than those for small-scale irrigators, despite the larger production effects of small-scale irrigators. The author suggested that the differences in income and consumption effects between the two types of irrigators could be due to lower

market engagement by small-scale irrigators compared with large-scale irrigators, with the implication that agricultural surpluses may affect household welfare more slowly if asset, input and food markets are less integrated.

Gender

Evidence from field-level studies and evaluation reports of donor-funded projects demonstrates that the success of irrigation in alleviating poverty will depend on the extent to which issues such as gender and water rights of the poor are taken into consideration (IFAD 2007; van Koppen and Hussain 2007; Zwarteveen 2006). Large-scale projects that improve women's access to land and water have been found to significantly improve household food and nutrition security and incomes (IFAD 2005). Participation by women in WUAs, in areas where women's role as farmers is widespread, has allowed them to articulate their interests and improve their understanding and knowledge of project matters. This has led to their participation in water distribution and maintenance, which, in turn, improved their access to water (Hulsebosch and Ombarra 1995; IFAD 2006).

Strategic priorities for the LSIFS

The availability of underutilized surface- and ground-water resources, the intensification opportunities, and improving access by farmers to input and output markets all suggest that the potential of the irrigated farming system as a whole for improving agricultural growth and reducing poverty remains high. The discussion below explores the way five alternative strategies of intensification, diversification, increased farm size, increased off-farm income and exit from agriculture can lift households out of poverty in LSIFS.

Table 13.5 shows estimated changes over time in the relative importance of the five strategies. With better water management, intensification remains the most important pathway out of poverty for households in the LSIFS. This implies 'more yield per drop' and will entail improving the reliability of water supplies and utilization of the full suite of crop productivity-enhancing measures, including best available germplasm, use of optimal doses of fertilizer and application of improved crop protection practices (e.g. integrated pest management). The evidence presented in Table 13.4 demonstrates that farmers in LSIFS can successfully intensify their production activities. Diversification is feasible where the irrigation management authorities allow this strategy to be implemented. The drive should be to get more value per unit of water, and this can be achieved through switching to higher value crops (fruits and vegetables), integrated farming enterprises (crop-livestock-aquaculture) (Figure 13.5) and addition of agroprocessing to increase value and employment per drop. The practice by many governments of allocating the limited irrigable land under public sector managed irrigation schemes to as many eligible farmers as possible means that increasing farm size will not be a major option in the LSIFS. Improved management and performance of large-scale irrigation schemes coupled with increased agricultural productivity could create off-farm employment opportunities that would increase off-farm income, as described earlier in the case of Office du Niger. For most households, the economic and social benefits derived from owning a plot within an LSIFS make exit from irrigated agriculture unrealistic and there is no widespread evidence of this occurring.

Figure 13.5 Oxen ploughing, Karfiguela irrigation scheme, Burkina Faso.

Source: Regassa Namara.

The question then is: what strategic interventions are needed to make these household strategies work to alleviate poverty? These interventions, summarized in Table 13.6, will be briefly discussed below under the main drivers of the system.

Population, hunger and poverty

In order to guarantee success, new LSIFS investments must be targeted to agroecological zones where population densities are high, where a process of intensification has already

Table 13.5 Relative importance of household livelihood improvement strategies in sub-Saharan Africa

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total ag pop	—	52	48	100
Intensification	3.5	5	3	4
Diversification	2	2	2.5	2.5
Increased farm size	2.5	0.5	2	1
Off-farm income	1.5	1.5	2.5	2
Exit from agriculture	0.5	1	0	0.5

Sources: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

started and where market opportunities are emerging. Unlike earlier investments, which paid little attention to measures to increase smallholder farmers' income, they should be planned and designed with poverty reduction and equity as explicit objectives. Undertaking pre-investment socioeconomic and farming system appraisals will allow site-specific social, economic and livelihood factors to be taken into consideration and will provide a good understanding of the way access to water and complementary inputs could be used to assist various household strata to improve their livelihoods. Irrigation is only one of a variety of livelihood strategies for farmers. However, when irrigation schemes are planned, the fact that farmers still cultivate rainfed plots, herd livestock, or engage in off-farm labour opportunities and migration is often overlooked. Without understanding how irrigation fits into other livelihoods strategies, inappropriate recommendations may be made that cannot fit into the labour constraints and multiple aims of different farming households.

Natural resources and climate

The quest to increase area under irrigation will entail development of new LSIFS. For these new schemes, lessons learned from fifty years of irrigation development should be borne in mind. For new irrigation development, the emphasis should be on sustainable intensification of agriculture that minimizes natural resource degradation. Environmental impact assessments within the wider landscape should be conducted during the preparation stage in order to identify alternative designs or mitigation measures. Looking at irrigation development from a watershed management perspective is often not a part of irrigation planning, but it is an approach that is sorely needed. Many schemes frequently suffer from siltation as a result of upstream land use practices. This challenge is also an institutional one as incentives for better land management by upstream users must be devised. Once the LSIFS is operational, monitoring and evaluation of environmental impacts and enforcement of mitigation measures, where negative externalities are created, will be equally important. Farmers' involvement in such monitoring and evaluation exercises will help ensure long-term sustainability.

Most studies predict that impacts of climate change will be more pronounced in Africa than in the northern hemisphere. Given the myriad other challenges confronting the agricultural sector, climate change may become a threat multiplier unless action is taken to improve the resilience of African agriculture. With more frequent occurrence of floods and droughts, irrigation can serve as a buffer against the predicted effects of climate change on rainfed agriculture. Irrigation must be a component of a climate-smart agricultural strategy that also includes proven in-situ soil water conservation methods at the field level.

Energy

A strategic priority going forward is to develop alternative renewable energy sources, e.g. solar and wind power, to pump water on LSIFS and supply electricity for other farm operations. The upfront investment cost of using these energy sources will be beyond the means of farmers and will need to be co-financed through public-private partnerships. In the long run, use of these energy sources will lower operational costs and will also contribute to a cleaner environment.

Human and social capital

Men and women farmers and farmer groups need training that is oriented to their specific constraints, challenges and needs. But the training required extends beyond simply managing, operating and maintaining irrigation schemes. Continuing training in skills ranging from leading and marketing their own organizations and businesses to record keeping will be critical for long-term success.

Years of structural adjustment programmes, partly implemented to curb public expenditure, have decimated the agricultural extension systems in many countries. The hard choice facing governments is either to rebuild and strengthen the national extension services or create the enabling environment for private sector and NGO intermediaries to step in and provide the needed extension support services. Whichever model is chosen, extension agents with relevant skills and expertise are needed to engage with communities in the design, operation and maintenance of irrigation infrastructure, and with farmers on efficient water use for irrigation and storage and marketing of irrigated crops. Research capacity and training in neglected aspects of irrigation management – water economics, social and institutional analysis, hydrology, hydrogeology, geographic information systems, remote sensing, meteorology, low risk cropping systems – will need to be strengthened in order to create a critical mass of professionals that can coordinate and manage the expected expansion of irrigation and enforce regulatory measures.

Science and technology

Informed policy, management and investment decisions depend on availability of fact-based evidence. At national and field levels, there is a need to improve the measurement, monitoring and evaluation of agricultural water resource availability, distribution and use. In gathering this data, African countries need to go beyond the traditional methods of data collection that rely on field assistants going from one field or household to another. Investments need to be made in hardware, software and personnel required to apply various remote sensing and earth observation decision-support tools to irrigation management.

In order to make use of the available but underutilized groundwater resources, detailed hydrogeological maps that provide information relevant for agricultural use such as aquifer depth, yield, transmissivity and recharge rates are needed. Various drilling technologies that are suited to different farming systems will also be needed as well as energy-efficient and affordable pumps for lifting water. New technologies and tools to improve water management and water use efficiency will help to enhance agricultural productivity.

Trade and markets

The agricultural growth and poverty reduction potential of the irrigated farming system is constrained by many factors that undermine farm-level profitability, including high input costs and lack of access to credit and markets. Farm-level profitability will be enhanced if farmers are empowered and assisted to operate within viable value chains that ensure access to input and output markets. This will lead to faster growth, higher incomes, and improved food and nutrition security for households in LSIFS. Building value-adding agroprocessing enterprises around irrigation schemes could create additional employment opportunities and linkages to the non-farm economy.

Table 13.6 Summary of strategic interventions for LSIFIS

<i>Drivers of LSIFIS evolution</i>	<i>Intervention</i>	<i>Implementers</i>	<i>Implications for farming system structure and function</i>
Population, hunger and poverty	<ul style="list-style-type: none"> • Irrigation investments in agroecological zones with high population densities • Research to understand households' livelihood strategies and where irrigation fits in 	<ul style="list-style-type: none"> • National governments and private sector investors • National governments, private sector investors and research institutions 	<ul style="list-style-type: none"> • Facilitate and provide incentive for intensification • Lead to irrigation recommendations that enhance livelihoods
Natural resources and climate	<ul style="list-style-type: none"> • Expand irrigation to make use of abundant land and water resources • Adopt a watershed perspective to irrigation planning and implement efficient irrigation water management practices 	<ul style="list-style-type: none"> • National governments and private sector investors 	<ul style="list-style-type: none"> • Increase opportunities for old and new irrigators • Minimize upstream and downstream social and biophysical problems • Increase farm productivity
Energy	<ul style="list-style-type: none"> • Investment in renewable (solar and wind) energy sources 	<ul style="list-style-type: none"> • National governments and private sector investors 	<ul style="list-style-type: none"> • Lower operational costs • Lower carbon emission
Human and social capital	<ul style="list-style-type: none"> • Capacity building of farmers • Investment in irrigation-related tertiary education and research 	<ul style="list-style-type: none"> • National governments, private sector investors and research institutions 	<ul style="list-style-type: none"> • Better train farmers to be able to manage irrigation infrastructure and grow irrigated crops profitably and in an environmentally friendly way • Increase capability to undertake research to improve LSIFIS
Science and technology	<ul style="list-style-type: none"> • Investment in new tools and techniques for collection of data required for irrigation planning • Investment in drilling technologies and energy-efficient pumps 	<ul style="list-style-type: none"> • National governments and private sector investors 	<ul style="list-style-type: none"> • Improve predictable supply of irrigation water to farmers
Trade and markets	<ul style="list-style-type: none"> • Improve access by farmers to finance and markets • Build viable value chains that include farmers 	<ul style="list-style-type: none"> • National governments and private sector investors 	<ul style="list-style-type: none"> • Increase farm-level productivity and profitability
Policies and institutions	<ul style="list-style-type: none"> • Improve coherence between irrigation, energy and environmental policies • Promote PPPs in LSIFIS development 	<ul style="list-style-type: none"> • National governments and private sector investors 	<ul style="list-style-type: none"> • Will provide appropriate and stable incentives to farmers • Expand area under irrigation and increase benefits to farmers

Policies and institutions

While much has been achieved in the way of policy and institutional reforms, much remains to be done. At the national level, irrigation policies need to be better integrated into agricultural growth and poverty reduction strategies. Measures to improve coherence between irrigation, energy and environmental policies are needed to remove ambiguity and contradictory measures and to allow policies to reinforce and complement each other. Continuing land tenure reforms will need to be pursued to ensure women's access to land in LSIFS. Policies and institutional arrangements that will create the right balance between the role of government and roles best performed by other actors – private sector, civil society, farmers' associations – as well as effective coordination and negotiating mechanisms among them will also be needed. In this regard, the new models of public-private partnerships (PPPs) that are being tried out in many countries offer opportunities to accelerate and better manage new investments as well as rehabilitate the dysfunctional irrigation infrastructure that has hampered the growth of many LSIFS. But PPPs in irrigation are relatively new, and especially in the context of SSA, much piloting, learning and evaluation is still required. This should be a priority given the potential payoff.

Conclusions

The potential of LSIFS and irrigation in general to improve food security, reduce poverty and promote agricultural growth is yet to be fully tapped in Africa. The availability of underutilized surface and ground water, the growing demand for staple foods, fruits and vegetables and continuing growth in intra- and inter-regional trade all suggest that the potential of the irrigated farming system to achieve desired objectives remains high.

The analysis presented shows that policy and institutional factors, natural resources, science and technology, and trade and markets have largely shaped the evolution of LSIFS since the late 1950s. Assessment of the performance of LSIFS, based on productivity, sustainability and human development outcomes, indicates that while performance has improved over time, much remains to be done. Predictable water supply, better irrigation management practices at field level and appropriate use of agronomic inputs are needed to raise agricultural productivity and farm profitability and to simultaneously reduce natural resource degradation, including problems of waterlogging and salinization.

Intensification, diversification and increased off-farm income represent feasible pathways for households in the LSIFS to move out of poverty. Strategic priorities to bring about the required change in the farming system include PPPs to increase and better manage investments in LSIFS; improving access by farmers to finance, input and output markets; improving extension support services; reforming land tenure to guarantee access of women farmers to irrigated land; and introducing alternative renewable energy sources for water pumping and other farm operations.

Implementation of these measures and lessons learned from past failures and successes will ensure that LSIFS can play an important role in improving food security, livelihoods and agricultural growth in the years ahead in Africa.

Note

- 1 'Small-scale irrigators' refer to farmers in a small-scale irrigation scheme of approximately 50 ha, while 'large-scale irrigators' refer to farmers in a community-managed irrigation scheme of more than 300 ha.

References

- Aw, D. and Diemer, G. (2005) 'Making a large irrigation scheme work: A case study from Mali', *Direction in Development*, World Bank.
- Barbier, E.B. (2003) Upstream dams and downstream water allocation: The case of the Hadejia-Jama'are floodplain, northern Nigeria. *Water Resources Research*, vol. 39, no. 11, 1311, doi:10.1029/2003WR002249.
- Barbiéro, L., Cunnac, S., Mané, L., Lapperrousaz, C., Hammecker, C. and Maeght, J.-L. (2001) 'Salt distribution in the Senegal middle valley: Analysis of a saline structure on planned irrigation schemes from N'Galenka creek', *Agricultural Water Management*, vol. 46, pp. 201–213.
- Barry, B., Namara, R.E. and Bahri, A. (2009) 'Better rural livelihoods through improved irrigation management: Office du Niger (Mali)', in R. Lenton and M. Muller (eds) *Integrated Water Resources Management in Practice: Better water Management for Development*, Earthscan.
- Boelee, E. and Madsen, H. (2006) *Irrigation and Schistosomiasis in Africa: Ecological Aspects*. Colombo, Sri Lanka. International Water Management Institute.
- Borgia, C., García-Bolaños, M. and Mateos, L. (2012) 'Patterns of variability in large-scale irrigation schemes in Mauritania', *Agricultural Water Management*, vol. 112, pp. 1–12.
- CFI (2013) *Revamping the Gezira Scheme: Sudan Seeks Food Security with Rice*. <http://cfi.co/africa/2013/08/revamping-the-gezira-scheme-sudan-seeks-food-security-with-rice/>.
- Cotula, L., Vermeulen, S., Leonard, R. and Keeley J. (2009) *Land Grab or Development Opportunity? Agricultural Investments and International Land Deals in Africa*. International Institute for Environment and Development (IIED).
- De Wit, M. and Stankiewicz, J. (2006) 'Changes in surface water supply across Africa with predicted climate change', *Science*, vol. 311, no. 5769, pp. 1917–1921.
- Dillon, A. (2010) *Do Differences in the Scale of Irrigation Projects Generate Different Impacts on Poverty and Production?* IFPRI Discussion Paper 01022.
- FAO (2005a) *Irrigation in Africa in Figures*. Aquastat survey 2005, FAO Water Report No. 29.
- FAO (2005b) 'Nigeria', in *Irrigation in Africa in Figures*. Aquastat survey 2005, FAO Water Report No. 29.
- FAO (2011) *The State of the World's Land and Water Resources for Food and Agriculture: Managing Systems at Risk*. FAO and Earthscan.
- FAO (2016a) AQUASTAT database. www.fao.org/nr/water/aquastat/data/query/index.html?lang=en.
- FAOSTAT (undated) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- Gebregziabher, G., Namara, R.E. and Holden, S. (2009) 'Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia', *Agricultural Water Management*, vol. 96, pp. 1837–1843.
- Guvele, C.A. (2001) 'Gains from crop diversification in the Sudan Gezira scheme', *Agricultural Systems*, vol. 70, pp. 319–333.
- Hamid, S.H., Mohamed, A.A. and Mohamed, Y.A. (2011) 'Towards a performance-oriented management for large-scale irrigation systems: case study, Rahad scheme, Sudan', *Irrigation and Drainage Systems*, vol. 60, pp. 20–34.
- Hulsebosch, J. and Ombarra, D. (1995) 'Towards gender balance in irrigation management: experiences in Kenya South-West Kano Project', *Irrigation and Drainage Systems*, vol. 9, pp. 1–14.
- IDA (2007) *IDA at Work. Water for Food. Improving Services for the Poor*. World Bank.
- IFAD (2005) *Participatory Irrigation Development Programme (PIDP) in the United Republic of Tanzania: Supervision Report*. IFAD.
- IFAD (2006) *Upper East Region Land Conservation and Smallholder Rehabilitation Project (Lacosrep) Phase II. Interim Evaluation Report*. IFAD.
- IFAD (2007) *Gender and Water: Securing Water for Improved Rural Livelihoods – The Multiples-Uses System Approach*. IFAD.
- Inocencio, A., Kikuchi, M., Tonosaki, M., Maruyama, A., Merrey, D., Sally, H. and De Jong, I. (2007) *Costs and Performance of Irrigation Projects: A Comparison of Sub-Saharan Africa and Other Developing Regions*, IWMI Research Report 109. IWMI, Colombo.

- Kiunsi, R.B. (2006) 'The extent and effects of salinity and alkalinity in community base irrigation schemes in the dryland areas of Tanzania, Case study: Chali and Bahi irrigation schemes in Dodoma region', *Journal of Building and Land Development*, vol. 13, pp. 41–48.
- Kizito, F., Williams, T.O., McCartney, M. and Erkossa, T. (2013) 'Green and blue water dimensions of foreign direct investment in biofuel and food production in West Africa: the case of Ghana and Mali', in T. Allan, M. Keulertz, S. Sojamo and J. Warner (eds) *Handbook of Land and Water Grabs in Africa: Foreign Direct Investment and Food and Water Security*. Routledge, pp. 337–358.
- Lipton, M., Litchfield, J. and Faurès, J.-M. (2003) 'The effects of irrigation on poverty: a framework for analysis', *Water Policy*, vol. 5, pp. 413–427.
- MacDonald, A.M., Bonsor, H.C., Dochartaigh, B.E.O. and Taylor, R.G. (2012) 'Quantitative maps of groundwater resources in Africa', *Environmental Research Letters*, vol. 7 (024009). doi:10.1088/1748-9326/7/2/024009.
- Mather, D. and Kelly, V. (2012) *Farmers' Production and Marketing Response to Rice Price Increases and Fertilizer Subsidies in the Office du Niger*. MSU International Development Working Paper 129, Michigan State University.
- Nakano, Y., Bamba, I., Diagne, A., Otsuka, K. and Kajisa, K. (2011) *The Possibility of a Rice Green Revolution in Large-Scale Irrigation Schemes in Sub-Saharan Africa*. Policy Research Working Paper 5560. World Bank.
- Namara, R.E., Hanjra, M.A., Castillo, G.E., Ravnborg, H.M., Smith, L. and van Koppen, B. (2010) 'Agricultural water management and poverty linkages', *Agricultural Water Management*, vol. 97, pp. 520–527.
- Neven, D. and Reardon, T. (2004) 'The rise of Kenyan supermarkets and the evolution of their horticulture product procurement systems', *Development Policy Review*, vol. 22, pp. 669–699.
- Pavelic, P., Giordano, M., Keraita, B., Ramesh, V. and Rao, T. (eds) (2012) *Groundwater Availability and Use in Sub-Saharan Africa: A Review of 15 Countries*. International Water Management Institute, Sri Lanka.
- Ruffeis, D., Loiskandl, W., Spendlingwimmer, R., Schönerklee-Grasser, M., Bekele, S., Boelee, E. and Wallner, K. (2010) 'Assessment of potential environmental impacts of two large scale irrigation schemes in Ethiopia', *Ethiopian Journal of Development Research*, vol. 32, pp. 63–105.
- Saleth, R.M., Namara, R.E. and Samad, M. (2003) 'Dynamics of irrigation-poverty linkage in rural India: analytical framework and empirical analysis', *Water Policy*, vol. 5, pp. 459–473.
- Shah, T., Burke, J. and Villholth, K. (2007) 'Groundwater: a global assessment of scale and significance', in D. Molden (ed.) *Water for Food Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. Earthscan and IWMI.
- Sidibé, Y. and Williams, T.O. (2016) 'Agricultural land investments and water management in the Office du Niger, Mali: options for improved water pricing', *Water International*, vol. 41, no. 5, pp. 738–755.
- Umali, D.L. (1993) *Irrigation-Induced Salinity: A Growing Problem for Development*. World Bank Technical Paper No. 215. World Bank.
- van Asten, P.J.A., Barbiéro, L., Wopereis, M.C.S., Maeght, J.L. and van der Zec, S.E.A.T.M. (2003) 'Actual and potential salt-related soil degradation in an irrigated rice scheme in the Sahelian zone of Mauritania', *Agricultural Water Management*, vol. 60, pp. 13–32.
- van Koppen, B. (1998) 'Water rights, gender and poverty alleviation: inclusion and exclusion of women and men smallholders in public irrigation infrastructure development', *Agriculture and Human Values*, vol. 15, pp. 361–374.
- van Koppen, B. and Hussain, I. (2007) 'Gender and irrigation: overview of issues and options', *Irrigation and Drain*, vol. 56, pp. 289–298.
- Verwey, P.M.J. and Vermeulen, P.D. (2011) 'Influence of irrigation on the level, salinity and flow of groundwater at Vaalharts irrigation scheme', *Water SA*, vol. 37, pp. 155–164.
- von Braun, J. and Meinzen-Dick, R. (2009) *Land Grabbing by Foreign Investors in Developing Countries: Risks and Opportunities*. IFPRI Policy Brief 13.

- Williams, T.O. (2011) 'Exploiting local, regional and international demand', in K.K. Yumkella, P.M. Kormawa, T.M. Roepstorff and A.M. Hawkins (eds) *Agribusiness for Africa's Prosperity*. UNIDO, Vienna, pp. 135–164.
- Williams, T.O., Gyampoh, B., Kizito, F. and Namara, R. (2012) 'Water implications of large-scale land acquisitions in Ghana', *Water Alternatives*, vol. 5, pp. 243–265.
- World Bank (2000) *Sudan. Options for the Sustainable Development of the Gezira Scheme*. Report No. 20398-SU. World Bank.
- World Bank (2007) *Investment in Agricultural Water for Poverty Reduction and Economic Growth in Sub-Saharan Africa*. Synthesis Report, A Collaborative Program of AFDB, FAO, IFAD, IWMI and the World Bank.
- World Bank (2010a) *The World Bank and the Gezira Scheme in the Sudan. Political Economy of Irrigation Reforms*. World Bank.
- World Bank (2010b) *Rising Global Interest in Farmland: Can It Yield Sustainable and Equitable Benefits?* World Bank.
- World Bank (2013) *Growing Africa. Unlocking the Potential of Agribusiness*. World Bank.
- Zoomers, A. (2010) 'Globalisation and the foreignisation of space: seven processes driving the current global land grab', *Journal of Peasant Studies*, vol. 37, no. 2, pp. 429–447.
- Zwarteveen, M. (2006) *Wedlock or deadlock? Feminists' attempts to engage irrigation engineers*. PhD thesis, Wageningen University.

14 The arid pastoral and oasis farming system

Key centres for the development of trans-Saharan economies

Mahamadou Chaibou and Bernard Bonnet

Key messages

- Arid pastoral and oasis activity systems are located in the heart of vast arid areas. They combine agroforestry systems intensively managed with highly scarce water resources as well as the management of surrounding Saharan grazing areas of extreme variability and very low productivity.
- Oases are not isolated, insular systems in the middle of desert; they are integrated in trans-Saharan routes and networks which have allowed various commercial exchanges (livestock, agricultural products, salt, etc.) for time immemorial.
- Oases display a large diversity of situations in terms of natural resources, and their social and economic resource management dynamics range from high productivity to decline.
- They are strategic areas where social and economic development should be reinforced in the face of the growing control of the economy by criminal groups observed in the last ten years.
- Trans-Saharan economies should be revived through the enhancement of commercial linkages by promoting security as well as through water and oasis agroecological innovations.
- Development of economic activity specifically geared for the youth and new, more attractive economic production models should be promoted.

Summary

The arid pastoral and oasis farming system represents over 30 per cent of Africa's land area. It extends over seventeen countries in northern, western, eastern and southern Africa. The system features oases that are intensively cultivated using irrigation in desert or highly arid areas, and livestock husbandry on natural vegetation limited to the oases and their surroundings. Traditionally the system was centred on oases north of the Sahara. However, recent socioeconomic changes (economic control by criminal groups, illegal trafficking, insecurity, collapse of trans-Saharan tourism) and climatic trends (temperature rise, late onset of rains, floods) are creating a radically new situation in Sahelian zones as oases become a place for retreat, refuge and security, where inhabitants grow vegetables. The extensive livestock system involves small ruminants (goats) together with camels.

To make the best use of available water, oasis farmers combine several types of crop and animal production, but the level of intensification and productivity varies. Poverty is common and often severe, especially after droughts.

From the simplest to the most complex, all oasis systems are in tenuous balance because they are subject to multiple constraints. Population pressure has caused progressive fragmentation of family plots, which is constraining oasis development, along with the very rigid land tenure systems. Other threats include weak governance, insecurity linked to the control of extremist and criminal groups, the lowering of groundwater tables, and dune encroachment. For these reasons, governments urgently need to assist communities in establishing rules for sound natural resource management and conservation, and to provide financial support to allow access to factors of production such as animal traction, solar-operated water extraction, transport and market infrastructure, improved water points and especially, provide technical support to enable farmers to increase system productivity.

Introduction

The arid pastoral and oasis farming system is composed of oases or water points in desert or arid areas that are intensively cultivated using irrigation and are associated with a pastoral system in the periphery. The system is found in north Africa (Morocco, Algeria, Tunisia, Libya, Egypt), the northern regions of the Sahelian countries (Mauritania, Mali, Niger, Chad, Sudan), eastern Africa (Ethiopia, Eritrea, Djibouti, and Somalia), and parts of southern Africa (Angola, Namibia and South Africa) (Figure 14.1).

The system exists where surface water or shallow groundwater makes the ecosystem favourable to human activity, among large areas that are otherwise either unsuitable for human activities as is the case for the large Ténéré erg, the Djado, Aïr, Tibesti, and Ennedi mountains, or areas that have seasonal grazing resources which could not be sustained without water from the oasis (Assaba mountain range, series of Manga depressions, Tamourt Hodh, el Gharbi and el Chargui in Mauritania). Availability of permanent water in the oasis makes the use of vast surrounding expanses of highly unpredictable grazing lands possible. Agricultural activities are confined to fossil valleys, oases¹ and depressions² (where there is available water) (Figure 14.2). For example, the Aïr and Kawar in the Niger Republic, and the Adrar in Mauritania and Mali, are valleys in the desert where the watertable is shallow and where there is running water from the mountains.

The oasis system evolved in conjunction with other systems in surrounding or distant areas. In some countries, surrounding arid pastoral areas are a source of livestock feed for the oasis component of the system. In other regions, exchange relationships and interdependencies are established between oases and pastoral and agropastoral systems. Here, products such as onion, cabbage, garlic, dates and salt from oases are supplied to urban centres further south, and trade in the opposite direction brings manufactured goods, cereals and animals from pastoral areas.

In the north, desert oases have historically been essential, strategic locations in trans-Saharan routes: the most famous are Bilma (Niger), Ouardane (Mauritania), In Salah (Algeria), Taoudeni (Mali), Iférouane, Chinguetti (Mauritania), Kufra, and Murzuk (Libya). Beginning in the tenth century, these caravan roads were regularly used and contributed to a strong cultural and commercial partnership between the two sides of the Sahara. Societies who occupied these oases used them as a base for controlling vast land areas and the trans-Saharan trade (Figure 14.3).

Figure 14.1 Map of the arid pastoral and oasis farming system in Africa.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Despite their geographical isolation in vast arid or desert areas, oases are not confined environments, and the economic viability of the system depends on relations with the outside. For several centuries, income from trade caravans and taxation was higher than from oasis production; the oasis farming mainly aimed to contribute to the food needs of the oasis communities and travellers. Thus some oases have known great economic prosperity (oasis of Kavar, Niger). With the development of other means of communication and exchange including maritime transport, oases have lost the economic benefits associated with their relay function on caravan routes. Thus, they have experienced periods of decline.

In southern Africa, the system has the same complementarity between water points (surface or groundwater in shallow aquifers) where irrigation is practised and vast surrounding areas where livestock graze. In Namibia, farming revolves around the availability

Figure 14.2 Cereal cropping in oasis depressions of Goudoumaria, Niger.

Source: Institut de Recherches et d'Applications des Méthodes de développement (IRAM).

Figure 14.3 Map of trans-Saharan routes and oases.

of water. Homesteads and kraals are located at water sources. Nowadays, these generally include boreholes using windmills or diesel pumps to supply water to reservoirs and drinking troughs. As farm animals need to drink at least once a day, their foraging is restricted to feeding areas within walking distance of water points. Rainfall is insufficient for grass except after sporadic good rains, and sheep and goats depend on browsing the relatively abundant woody and succulent shrub vegetation (Mendelsohn 2006). Before the introduction of permanent farms in the late 1910s, pastoral nomads moved their live-stock and homes between seasonal water sources and grazing areas.

Overall description of the farming system and subsystems

This farming system covers about 30 per cent of the continent. However, agricultural activities are confined to spatially limited, suitable environments such as fossil valleys, oases and depressions (Figure 14.2). In 2015, the farming system (north and sub-Saharan Africa) hosted an estimated 67.2 million small ruminants, 13.8 million cattle, 6.9 million camels, 0.1 million pigs and 252 million chickens.

Human population in this farming system, estimated at 16.4 million (Table 14.1), is made up of various ethnic groups. Major groups include Tuareg, Kanuri and Tubu in the Niger Republic; Tubu (Teda and Daza) and Zaghawa in Chad; Moors and Toucolors in Mauritania; Tuareg and Arabs in Mali; Rufa'a, Kababish and Baggara in Sudan; Afar and Dankali in Ethiopia; Somali in Somalia; and Rendille and Sukama in South Africa. Their main activities include agriculture, animal rearing and caravan trading.

The extent of the farming system thus includes the central and irrigated core, as well as areas where cropping, animal husbandry (on vast areas of arid pasture land with mobile herds and herdsman), salt extraction, trade and communication take place (Godard et al. 1990; Retaille 1986; Riou 1988). The vitality or decline of the system depends on this overall set of activities.

Table 14.1 Basic system data (2015): arid pastoral and oasis farming system

<i>Item</i>	<i>Data</i>
Total human population (million)	16.4
Agricultural population (million)	7.6
Total area (million ha)	915
Cultivated area (million ha; % of total area)	0.35; 0.038
Irrigated area (million ha; % of cultivated area)	0.23; 67
Total livestock population (million TLU)	23.3
Major agroecological zone	Tropical warm arid
Length of growing period (average, days; core range, days)	12; 0–30
Access to services	Very low
Distance to 50k market (average, hr; core range, hr)	20.8; 10–10+
Agricultural population density (persons/total area; persons/cultivated area)	0.008; 21.7
Livestock density (TLU/total area; TLU/cultivated area)	0.03; 67.0
Standard farm and herd size (cultivated area/household; TLU/household)	0.3; 17.0
Extreme poverty (% of rural population)*	27

Source: Refer to Table 2.4.

*sub-Saharan Africa only.

Two components of an integrated farming system

The farming system relies on two closely connected components – the oasis component and the arid pastoral component – which cannot exist without one another. Oasis populations own large numbers of livestock due to the surrounding wide stretches of Saharan grazing land, and, in turn, the pastoral component exists due to the ability for livestock to take refuge and drink in oases. This complex and productive agriculture–livestock association is described in Figure 14.4.

Oasis component

Oases are made up of dense vegetation dotted with small intensively cultivated agricultural plots using groundwater from deep or shallow wells. The cultivated area is only 0.35 million ha or 0.04 per cent of the farming system's total area.

Survival of oases' agriculture depends on the mobilization of available water resources. Technically this can be done in various ways. Sahelian facilities are less developed than those observed in north Africa (*khettaras* of southern Morocco, *foggaras* in Algeria (Touat, Gourara and Tidikelt) or Iranian *qanats*). Modes of water collection are specific to the various kinds of oases, basins and wadis, for example shaduf, delou, manual collection, or the use of gourds in inter-dune oasis depressions supplied from a shallow watertable, as found in the region of Diffa, Niger. The use of pumps is spreading rapidly wherever conditions are suitable (e.g. depth of watertable, financial capacity of producers, availability of land and mechanical spare parts).

Figure 14.4 Activities and interactions in the arid pastoral and oasis farming system; the three-storey agroforestry system and integrated pastoral system of the Kawar oasis, Niger.

Source: Dollé (1985).

Fine technical control of the water resource is traditionally associated with complex social organization that governs water and land management rights and usage in these highly coveted areas. However, traditional community water management is gradually changing and sometimes declining, particularly in areas north of the Sahara.

Farmer knowledge covers a wide range of experiences accumulated in the field to manage resources. Faced with harsh production environments and survival imperatives, rural populations have developed a range of technological innovations in agriculture, including agroforestry, assisted natural regeneration and soil fertility management practices.

Originally the cultivated core of these ecosystems was mostly made up of natural palm groves. Their management intensity has fluctuated over time according to local social and economic conditions. The local agroforestry system is dominated by the doum palm (*Hyphaene thebaica*) and the date palm (*Phoenix dactylifera*), which are present in all social and economic activities pursued by residents of oases and depressions. The date palm has multiple uses and provides fruits, wood (for building house roofs and door frames), fibre from leaves (for baskets, mats, fans and containers for transporting dates and salt³ on the back of camels), and dead branches (as garden fences or firewood for cooking). Fruits of the doum palm (the fine dried kernel) are a major product (more than 15 tonnes are harvested annually in the region of Agadez, Niger). Other tree species found in this system include desert date tree (*Balanites aegyptiaca*), jujube (*Ziziphus mauritiana*) and *Acacia nilotica* in Niger, Chad, Mauritania and Sudan. Fruits from these species and their marketing provide substantial income for oasis populations. Some grass species such as *Panicum turgidum*, *Aristida mutabilis*, *Cymbopogon* spp. and *Stipagrotis pinguens* are also harvested and sold as hay in urban centres, providing further income for farmers.

In more developed systems, the core of the oasis consists of a palm grove under which two vegetation storeys are found when water resources are sufficient, for example, fruit trees (pomegranate, apricot, fig) beneath which are cereals, alfalfa or vegetables (Box 14.1). In major wadi beds or depressions, for example a number of oases organized around a *guelta* and *wadi* (Lagueila in Mauritania, Ounianga-Kebir in the Ennedi in Chad, Oubankort in the Adrar of Ifoghas in Mali), flood recession farming is possible (see Chapter 11 this volume for a description of recession farming). Although very intermittent, this type of farming can contribute significantly to the cereal supply of oasis populations.

The most common cultivated cereal crops are sorghum, wheat, maize, rice and barley in descending order of importance. Fodder crops such as alfalfa (*Medicago sativa*) are also grown. Nevertheless, the most important agricultural crops are vegetables and fruit trees. Fruit tree production is increasing in importance. Species include mandarin, mango, grapefruit, pomegranate, grape, olive and date palm.

The irrigated core of oases is organized in several plots with individually operated water management systems (Figure 14.7). Plots can be isolated from each other in certain types of oases (for instance in the series of small oasis basins in Goudoumaria, Niger) or contiguous within a single, general irrigation system.

Irrigated gardening is the main agricultural activity practised throughout the year. The most important vegetable crops are beans, sugar cane, cassava, yam and sweet potato. Others include onion, tomato, spices, garlic, potatoes, lettuce, eggplant, peppers and cucurbits. Cash crops such as groundnut, cotton and other oilseeds are also produced.

Box 14.1 The Kavar oasis in the heart of the Nigerien Sahara

Halfway between the Ténéré Desert and the mountains south of the Saharan north Djado, there is a string of Kavar oases located at the foot of a cliff extending over 100 km where water from scarce rainfall (12 mm per year) miraculously accumulates. The presence of water results in flourishing date palm plantations and makes commercial extraction of rock salt possible (Figure 14.5). With this water in the desert, Kavar (over 40,000 inhabitants) has for centuries been a crossroad and a strategic stopover for caravans on the main trans-Saharan road linking central Nigeria and Libya via Diffa, Bilma Ngourti and Murzuk (Figure 14.6). The oasis economy is based on trans-Saharan trade, bartering and transport of four water-demanding commodities – date palm, salt, vegetables crops and livestock – which are considered the backbone of oasis society, as well as labour migration. Date palm is the main cash crop, contributing 40–60 per cent of annual household income. Date palms are planted traditionally at a density of 100 trees per hectare (each date palm belongs to a distinct family). The palm is also grown in association with vegetable or forage crops which together have high annual water requirements, estimated at 17,000 m³, provided by extracted groundwater. In addition to dates, export of salt and soda can represent nearly 50 per cent of the income of oasis farms. Kavar's salt production represents 90 per cent of Niger's total national production and is exported nationally and subregionally. The great Azalaï caravan still provides the bulk of a triangular barter system: Bilma salt is carried to Agadez and the Niger River region. The Tubu and Ouled Slimane camel caravans from the Diffa Region (eastern Niger) transport livestock (camels and small ruminants) across the Ténéré to Bilma and Dirkou to exchange for salt and dates. The caravan then goes back to the Kano area, Nigeria – a distance of over 800 km – to exchange these oasis products for cereals that are transported to camps around Dilia on the southern edge of Ténéré. Exchanges are also carried out on tractor trailers.

Vegetable crops (the largest production being alfalfa) are grown on 3 to 10 per cent of the cultivated area and may contribute up to 25 per cent of annual income. Primarily produced for self-consumption (40 per cent), the surplus is sold locally or processed (dry). Residues of vegetable crops are valued for livestock. Management of irrigation water is paramount. The water is drawn from communal wells (15–20 m) or privately owned wells equipped with individual pumps. Collectively managed water is also available from 'water towers' originating from boreholes and springs at the foot of the cliff, which may be located four to five hours upstream from the oasis. Irrigation systems or networks called the 'Californian system' that permit the cultivation of large areas and result in good yields are increasingly used. Market-oriented gardening in the Kavar receives many technical inputs via migrants who go to work for a few years in Libya and return with practical and innovative techniques for oasis farming and fertilizing poor desert soils. About 30–40 tonnes of manure per hectare are needed annually for the production of vegetables. Sale of livestock has an important role for savings and pension.

Figure 14.5 Salt water pool in the oasis of Argui in Kavar, Niger.

Source: IRAM.

Figure 14.6 Map of oases in Bilma department, Niger.

Figure 14.7 Oasis irrigation system, Niger.

Source: IRAM.

Oases are also important for livestock production. Management is sometimes intensive with crop residues used as fodder supplements for livestock, and manure used as a precious input to vegetable gardening.

The household is the foundation of the community and its economy. Box 14.2 describes a typical household in the oasis component of the system. Women play a vital but often overlooked role in the agricultural oasis farming system. Women specialize in livestock management (unlike the pastoral system) and domestic crafts including manufacturing mats, fans, baskets and other woven artefacts. In some oases, they may have very small plots for vegetable cropping, in particular cucurbits, and engage in salt production. When it comes to marketing the production, men seem to take over. This is usually due to the fact that markets are outside the formal economy of the household, and women are confined to the household, unable to participate in markets.

Mineral salt extraction for human and animal consumption is the most important economic activity in some oases where it provides employment for 90 per cent of the population. The salts are traditionally extracted in a mixed soil paste for animal consumption and crystallized for human consumption.

The oasis component is characterized by technological weaknesses: irrigation equipment is traditional, and water collection and distribution pipes are generally not

covered. Technical support for producers, whether by state technical services, projects or NGOs, is very weak in terms of works maintenance rules, water use, and organization and improvement of cultural techniques.

Box 14.2 A typical household in the oasis component of the farming system

A typical oasis farm household in Niger cultivates around 0.85 ha. Crops usually include onion, tomato, garlic, wheat, maize and dates. Tree products are sold (fruits) or used for animal feed (leaves). Average crop production (for all crops combined) is 10.1 tonnes per year. The herd is composed of 20 small ruminants, 10 camels, 5 to 7 donkeys and 2 head of cattle, with an offtake rate of about 7.5 per cent. The household has six to seven persons, with three or four of these actively farming. The farmer uses organic manure from his own farm. Household income is 60 per cent from the sale of agricultural produce (garden produce, fruits, dates), 20 per cent from livestock products and 20 per cent from other sources. A portion of production is allocated for home consumption, but this depends on the market especially during the lean period or when yields are low. About 49 per cent of households are unable to meet their food requirements. Nutrition is low particularly for one- to five-year-old children in the poorest households. Because of budget constraints or financial needs, poor consumers sell nutritious foods such as milk, eggs and meat and buy cereals, although purchase of cereals is limited by increasing prices. Estimated meat consumption is less than 23 kg/person/year. Energy intake is estimated at 1262 kcal/day, which is below the daily requirement of 2100 kcal. Off-farm income represents a major livelihood source for many households. It consists of remittances and income from migration, or income from work in mines, construction sites and tourism. Women perform all household activities and play a central role in the organization of the household. They have very limited time to engage in income-generating activities and therefore play a minor role in earning household income.

Arid pastoral component

The arid pastoral component of the system is characterized by extensive livestock production taking place on wide expanses of land surrounding oases. It involves small ruminants (goats) associated with camels, the only animals capable of providing transport within Saharan areas. The stocking rate per unit area is extremely low. Animals are fed on plant biomass produced outside oases, which relies on erratic rainfall. For this reason, herders adopt highly responsive and flexible grazing strategies reliant on the natural environment. Camel herds, which do not depend on daily watering, exploit pasturelands which are sometimes very distant from the oasis (e.g. 100 km). Herdsmen carry water for their own needs or drink milk only. Camels' primary food resources for most of the year alternate between ephemerophytic pastures fed by rare rainfall, and winter grazing lands dominated by *Cornulaca monacantha*, which are widely sought after in desert zones.

Given their relatively high population density, oases are a significant source of supply and demand for animal products. Camels are sold as draft animals for oasis agriculture and meat for local markets. Local meat is primarily camel meat; small ruminant meat is rare and very costly. This component represents the largest component of animal production in the overall farming system. Livestock production strategies differ in the oasis and arid pastoral components of the farming system (Box 14.3).

Box 14.3 Livestock management in the oasis and surrounding arid pastoral plateaux in the Kavar oasis

Livestock management in the Kavar oasis is highly intensive and uses animal compounds. Animals that are used for transport (camels and donkeys) – and small ruminants – are raised in the backyard home compounds owned by Kanuri people (vegetable growers and traders). Livestock are the catalyst and cannot be isolated from the rest of the oasis agroecosystem. Their rich diet includes grazed forage from the immediate surroundings of the oasis, cultivated fodder (irrigated alfalfa), groundnut and vegetable crop residues and date palm residues (crushed date stones and damaged dates). Besides providing meat, mostly for home consumption and social and religious ceremonies, the main purpose of raising livestock is for organic matter and fertility transfers. Livestock manure provides a valuable input to vegetable production. Animals are rarely marketed; they are expensive and do not satisfy local demand. (During periods of religious celebrations, livestock are imported from elsewhere in the country.) The Kavar oasis is a complex and intensive system with strong interactions between perennial and annual production, and fertility transfers that are indispensable to plant production in an arid environment (the first dunes are only a few hundred metres from the oasis). This delicate interweaving of various elements helps to preserve system sustainability and sustain life in the desert.

The arid pastoral production component around the Kavar oasis is exclusively based on camels belonging to Tubu herders, for whom pastoralism provides nearly 80 per cent of their income. They use pasture on scarcely and irregularly rainfed dune areas; most pastures are very distant from the oasis, and sometimes as far as 80 km. Animals are left wandering on their own with irregular supervision often limited to ensuring their access to drinking water. This component is characterized by a high level of opportunistic pasture utilization including abandoned or uninhabited palm groves and areas of low rainfall. Camels are watered from oasis wells or more rarely from truck tanks. These camels will be used for renewing draught animals or to supply markets that demand camel meat (Libya and nations of the Arabian Peninsula).

While both components rely on water from the oasis, the integrated oasis livestock component and the extensive arid pastoral component have few interlinkages in terms of livestock food and management. These two system components utilize different vegetation strata and make different use of livestock: draught and export for extensive systems and home consumption for the integrated oasis system.

Source: Christophe Bénard, IRAM.

Subsystems

Four major subsystems of the arid pastoral and oasis farming system are proposed following the classifications outlined by Dollé (1985) and Toutain et al. (1989) based on the dynamics and intensity of oasis management:

- Type A. Gathering oases. Supplementary irrigation of palm plantations becomes increasingly impracticable because of a lack of water or the difficulty in extracting it due to sand accumulation or labour shortage. Oases are being abandoned and only a date-gathering activity persists (Djibouti palm plantations).
- Type B. Pastoral oases. Water resources are available and a significant proportion of palm plantations access shallow groundwater. There is no understorey cropping and management activities are kept to a minimum (pollination and gathering of fruits). The main activity is not palm agriculture, but seasonal transhumant pastoralism. Some family members are left behind with a few animals (Assaba palm plantations, Mauritania).
- Type C. Fallback oases. These are places where farmers who have recently lost their livestock come back to settle. They practise palm agriculture with occasional understorey crops and gradually rebuild their herds (Adrar palm plantations, Algeria).
- Type D. Cultivated oases. Palm plantations here are in good condition, with understorey layers of intensively managed crops making up a proper oasis agroecosystem. The watertable is shallow. Raising livestock is common and byproducts of crops are used (palm plantations of the Draa valley, Morocco).

Trends and drivers of change across the system

The development of oasis agriculture cannot be separated from the history of two older agrarian civilizations: Mesopotamia and Egypt along the Nile (Toutain et al. 1989). During the first millenium BC farming techniques were disseminated along the shores of the Mediterranean and pre-Saharan fringes via major tradeways reaching the Sahel, complemented by caravan routes up to 500 BC through which camels were introduced. Water channelling, irrigation techniques, agricultural practices and crop species spread gradually along caravan routes linking a series of oases. After centuries of selection pressure in the oases, traditional management techniques have led to the development of very well-adapted agricultural plant and animal genetic material. The abolition of slavery, civil peace since the 1960s resulting in infrastructural development such as clinics and schools, the extension of the road network and mechanization have induced important changes. Since World War II, there has been a gradual increase in population and increased trading of agricultural goods. The following paragraphs outline the key trends and drivers affecting the farming system.

Population, food security and poverty

Population in the system grew at a high rate of 2.3 per cent per annum between 2000 and 2015. With 27 per cent of the rural population earning less than US\$1.25 a day, the arid pastoral and oasis farming system has the second-lowest incidence of extreme poverty among African farming systems. Markets have the potential to absorb the entire local production from the farming system; however, delivery is a constraint – production areas are far from major urban centres and transport infrastructure is highly constrained. Successive droughts in recent decades have contributed to increased poverty.

When faced with food insecurity, households adopt various strategies: (i) reduction in the number of daily meals, (ii) sale of livestock and household goods, (iii) debt or land mortgage, (iv) migration or involvement in new income-generating activities. In high-risk areas all household members are involved in helping solve the food problem.

Natural resources and climate

Agroecological sustainability is threatened by the degradation of oases' biophysical environment and natural resources. The main threat is reduced water resources. In north African oases and Saharo-Sahelian depressions, successive droughts since the late 1980s have reduced available water and resulted in increased pressure on water and land for cultivation. Contributing to increased water use are the livestock keepers who lost livestock during drought and now cultivate the pastoral periphery of depressions and wadis. Climate change has also affected this system, with a decline in rainfall in upland areas, which has reduced recharge and lowered groundwater levels. A shortage of irrigation water has resulted in reduction of the cultivated area (e.g. Goudoumaria basins).

The other cause of decreasing water resources is overuse of groundwater through uncontrolled proliferation of pumps and wells, even though modern pumping systems are not yet very common in sub-Saharan areas. Water overuse can have several origins:

- adjacent urban development which creates competition for water; this is generally detrimental to the needs of palm plantations
- proliferation of individual, private pumping systems near old palm plantations which allows farmers to free themselves from rules and constraints of collective water use. This can lead to a gradual depletion of water in oases (e.g. Tafilalet, Morocco; Wilaya of Adrar, Algeria; low ground of Goudoumaria, Niger; Wadi Doum, Chad)
- the use of fossil aquifers to create new wells and increased intensification of date palm plantations is also an important ecological risk because deep pumping of water from these aquifers can cause non-renewable resource depletion (e.g. Maghrebien continental intercalary).

Sand accumulation (Figure 14.8) and soil salinization can also contribute to the decline of oases and affect their sustainability. Such processes are observed in the Manga basins in Niger (Ichaou and Guibert 2009), Kanem in Chad and in oases located along the ergs of Chinguetti in Mauritania. Another threat is bayoud's disease, which may destroy palm trees. This fungal disease has spread throughout north Africa and has been a research topic in eastern Niger. Apart from resistant varieties of dates, there is no effective treatment against the disease. Farmers think that this disease is a natural constraint of their environment and that they should live with it.

Energy

Fuelwood represents a major source of renewable energy, but uncontrolled use can lead to unsustainable harvesting. More than 70 per cent of the population in sub-Saharan Africa has no access to electricity. This constraint is particularly severe in rural areas including oasis centres. In Niger, for example, household access to electricity in 2006 was 47 per cent in urban areas and only 0.4 per cent in rural areas (especially in remote areas) (Institut National de la Statistique et Macro International Inc 2007). This is due to a

Figure 14.8 Large Saharan depression threatened by sand accumulation.

Source: IRAM.

combination of several adverse factors: low density and dispersed settlements, remoteness of the network, very low-income populations, lack of profitability of rural electrification projects, lack of technical capacity of private actors, limited investment capacity of national public services, and low access to credit for local, private power producers in rural areas. An effort is being made by multilateral and bilateral donors, national governments and the private sector to improve the situation. Support for energy governance is a priority for international aid for west Africa (e.g. the European Union).

Human capital, gender and agricultural knowledge

The diffusionist, top-down agricultural research approach has led to the development of technologies which are not always adapted to farmers' realities and only rarely take traditional knowledge into consideration. Thus, traditional farming techniques remain the norm, although some new techniques are more water efficient and allow better integration of crops and livestock. The lack of extension (see 'Institutions and policies' sub-section below) means that there is little transfer of agricultural knowledge apart from through traditional means. Emigration of youth and their enrolment in trafficking networks and the breakdown in community management of natural resources, in particular water, are leading to reduced knowledge transfer within the farming community. Low public investment in education and health, and the lack of economic integration, also

constrain household capacity to obtain the knowledge needed to improve agricultural and pastoral productivity, develop value-chains, or to earn off-farm income. Women's participation in new enterprises and farming techniques is inhibited by limited access to extension services. Resources and means of transport to remote markets are their biggest challenge. Their need to travel can also be hampered by their role as mothers.

Science and technology

Low capacity to invest in modern farm production techniques and agricultural materials, and households' limited diversity of income sources, explain the use of traditional extensive cultural methods in the farming system. To improve livelihoods, agricultural production needs to be increased and needs protection against physical (e.g. pests) and technical threats. Constraints faced by farms include irrigation water availability and distribution, drainage, salinity and maintenance of water distribution networks. While wells, boreholes and water reservoirs facilitate irrigation, technical support services are very poor in the areas of operation and maintenance (O&M) of irrigation infrastructure, determining collective water use for irrigation (amount to apply, method of application), and collective organization of O&M, water use and improved cultivation techniques.

There are also difficulties related to the lack of local, small-scale processing (postharvest) and preservation of horticultural products. Low allocation of research funds, and remoteness and difficult access, are added constraints in this system.

Markets and trade

Isolation and inadequate public and private investment to coordinate markets are bottlenecks that reduce the system's performance. Nevertheless, there have been remarkable developments in less isolated areas such as the valleys of southern Air in Niger. For instance, activities in the Tabelot gardens at the foot of the Air Mountains were first supported by NGOs with projects catering for livestock herders who were ruined by the 1973 and 1984 droughts. Driven by markets, irrigated vegetable growing has flourished remarkably since the late 2000s in response to increasing demand in coastal countries for onion (called 'white gold of Air') (Penot et al. 2002). Some valleys of the Agadez region, Niger, have taken the place of more classical onion production zones through dynamic planning and development (small-scale irrigation investments, technical advice, loans, etc.) led by local organizations supported by NGOs and technical partners. The same situation is observed in some wadis in Chad, near Abeche, where road development facilitated substantial onion production and trade.

However, a very high level of insecurity, loss of state control and trafficking of illegal goods are crippling development in these areas. The wave of high insecurity since the late 1990s has reinforced isolation by making communication risky and has reduced commodity commercialization. The impact is strongly felt as many households derive most of their income from marketing and particularly transport of products. The gradual closure of trans-Saharan roads since the late 1990s in Mali and Niger has economically stifled agrosilvo-pastoral farming in oases. The 2012 northern Mali conflict is a particularly striking example of how weak state governance and support have contributed to the control of the territory by extremist groups and drug and weapon trafficking networks. This was also the case in northern Niger with the Tuareg rebellions of 1990–1995 and 2007–2009 and northern Chad during the years of the Chad-Libya conflict.

Road transport could be developed in some countries such as Chad, Niger and Mauritania to facilitate communication and trade with other centres. Political will exists as shown by the Trans-Saharan Highway Project. Camels are another means of transport in the desert. Even though slower than vehicles, camels can reach very distant cities (Tamanrasset-Khartoum caravan via N'Djamena) and camel transport is in full expansion. Ecotourism has not yet developed but could contribute to an improved economy in peaceful areas of Mali, Mauritania, Niger, Chad, Sudan and Somalia.

Institutions and policies

Land tenure problems include difficulties in land acquisition and inheritance, and land fragmentation as a result of increasing population and distinct ownership patterns for soil, water and palm trees.

Central governments provide little support to arid pastoral and oasis system areas. These areas are often marginalized and forgotten by decision centres, and the lack of funding to improve production impedes their development. After a dynamic phase during the 1980s to 2000s, research and extension have suffered from financial crisis and the closure of support projects in many countries. In this system, we estimate there is one technical extension agent for 2,000 agriculturally active persons. As extension agents are poorly resourced, the impact of their interventions remains very insufficient relative to support needs. Most agricultural banks in the system's countries (including Mali, Mauritania, Niger) were liquidated during the 1980s in the context of structural adjustment. However, some NGO development projects are granting micro-credit to rural actors. The average African government budget for the agricultural sector in 2010 was 6 per cent, despite 2003 Maputo commitments to achieve 10 per cent by 2008. It is similarly low in Niger and Mali, but with contributions from technical and financial partners in the agricultural sector, total expenditures for the sector reached 22 and 19 per cent in Niger and Mali respectively.

The European Union, the World Bank, the United Nations system, France, Belgium, and other countries and organizations have invested in pastoralism and continue to participate in resource mobilization. Investments in irrigation are supporting small-scale private irrigators through credit or subsidies for development of their operations, as well as new rural development schemes. Government institutions and civil society organizations are supporting communities through establishment and financing of micro-projects and income-generating activities. Credit lines for women, market cooperatives, micro-finance institutions and other support for grass root communities are benefitting risk-prone areas, although their quantitative scale and coverage are low, given the widespread poverty and vulnerability.

Political threats to the arid pastoral and oasis farming system include the current shift of traditional and state governance modes to control by mafia-like and extremist groups following geopolitical interventions of neighbouring and northern countries, which stem from the Libyan and Syrian crises that are largely controlled by international politics. One cannot overemphasize the need to re-establish security and rule of law to help this system exit the destructive spiral in which it is currently engulfed.

System and subsystem performance

It is very difficult to characterize performance of these systems because of their diversity and the range of products. Performance also depends on subsystem type as defined in

Dollé's typology of gathering and survival oases (see 'Subsystems' above). Examples of fully developed oasis agroecosystems with palm plantations in equilibrium showing three cropping storeys (palm trees, fruit trees, understorey of irrigated cereal and cash crops) are numerous yet isolated. Most palm plantations in Mauritania do not meet this description. In Djibouti, most palm plantations are used for gathering. According to Toutain et al. (1989), performance of Moroccan palm groves of the Draa valley, Gheris and Ferkla is the highest in this system. This higher productivity is thought to be due to the association of intensified cropping and sedentary livestock (mainly sheep and some cattle or goats), with livestock production providing high levels of animal manure (25 t/ha/year). In the sheep production system, the D'Mane breed (Dollé 1982) also has an exceptional reproductive capacity (two lambings per year and many lambs per lambing) making it an ideal breed for a fully integrated intensified oasis farming system.

Average area per farmer in oases in Niger is 0.85 ha. The average oasis production per farmer (all crops cultivated) is estimated to be about 10 tonnes, with about 21 per cent consumed by the household (Pini and Tarchiani 2007a). In the Djado valley in Niger, oasis production is based on two other activities: date collection and salt extraction. Date production is very important and can reach 5,000 tonnes per year in some oases (50.9 ha/oasis) (Pini and Tarchiani 2007b). Dates are a much appreciated food and are bartered by nomads living in these desert areas to obtain cereals.

The declining yield of major oasis crops in past years is due to a range of factors, including the dominance of small traditional family farms (0.3 ha per household of 5.5 persons); limited use of modern inputs compared to needs; and limited access to land, research, extension, agricultural technical support, credit and mechanization. System performance is also reduced due to insufficient water and lack of access to technology and agricultural inputs. It is clear that in this situation, living conditions of local people are bound to deteriorate rapidly. This could be alleviated with improved rural productivity or development of the labour market outside of the agricultural sector.

The following directly or indirectly constrain productivity increases:

- remoteness that reduces opportunities for commercial use of salt and dates
- low technological level preventing increases in production and processing
- insufficient basic infrastructure as well as a lack of producer organizations
- increasing insecurity and economic suffocation of these areas resulting from a lack of government presence and control by extremist groups and traffickers.

Promising system management and restoration technologies

To control declining groundwater resource associated with generalized sand accumulation, the introduction and dissemination of more efficient technologies for water drainage as well as sand accumulation control are needed.

More than twenty years of struggle to control sand deposition in basins have led to several successful experiments, with the following general, qualitative lessons (Ichaou and Guibert 2009). Positive results can be observed after three to four years of dune stabilization work using several techniques: wattles based on *Leptadenia pyrotechnica* or doum palm fronds, manure from small ruminants allowing rapid herbaceous plant cover, and planting woody trees such as *Prosopis chilensis* and *Acacia senegal*. Impacts of such sand control systems managed by oasis farmer organizations have been: mobile dune soil becomes more stable, pioneer vegetation reappears during the following rainy season and accumulated

organic matter enhances soil physical properties. Herbaceous vegetation cover brings the various elements together making life possible, leading to a new equilibrium. Seedlings are weak but moisture in the profile of the stabilized dune ensures easier root development. This is the case for *P. chilensis*, which grows to a spectacular size in only three to four years.

Implementing a concerted strategy jointly with local desertification control organizations certainly does not stop this phenomenon, but it facilitates displacement of the sand drop zone from areas that are deemed very sensitive towards less risky locations. Because they cause damage to natural resources, deforestation (logging) and bushfires should be controlled. In addition, sand dune control should be done in a gradual, incremental manner starting with the most fragile areas and moving towards locations where a preventive strategy is more suitable. In the medium term (five to ten years), the first selective harvests (a few stems) should be planned in order to motivate local people.

Strategic priorities for the system

From the simplest to the most complex, these arid pastoral and oasis systems are in delicate balance because of the numerous constraints they face. These include:

- population pressure resulting in a progressive fragmentation of family plots, which is incompatible with oasis development
- rigid land tenure inherited from past management systems, which impedes value-addition of unmanaged lands
- competition for water resources between traditional and mechanized water use systems with the latter leading to high water consumption, a decline in groundwater levels and a lack of system sustainability
- expansion of diseases such as bayoud that have destroyed half of Moroccan palm groves (Toutain et al. 1989) and now extend to sub-Saharan oases
- lack of trans-Saharan and sub-regional project planning for trade and development
- changes in social groups and production-oriented relations between oases and their national and international surroundings
- worrisome religious extremists and mafia-like traffickers that can take control of local economies.

These old and new constraints act to weaken the arid pastoral and oasis systems developed by local farming societies in oases over past centuries. There is an urgent need to help maintain these systems in balance; save, rehabilitate and extend existing oases; and put emphasis on implementing a series of major initiatives for the sustainable development of these systems.

Poverty escape pathways

The banditry, armed movements, criminal economy (e.g. migrants, cigarettes, drugs, arms) and utter physical insecurity of people and goods present in most arid pastoral and oasis systems of northern Mali, northern Niger and eastern Mauritania precludes the development of intensification, diversification and other strategies to escape poverty. Until security and rule of law are reinstated, exit from agriculture to join such trafficking networks may, unfortunately, be the prevailing strategy for agropastoral farmers in the present system.

Poverty escape strategies for the poor have remained relatively unchanged since 2000 (Table 14.2). Spatial expansion of agriculture in this system is constrained. However, provided security of roads is ensured to supply Saharan urban centres and promote livestock trade, the intensification and diversification pathways can be pursued by households who can afford basic crop and livestock technical support services from the government. Less resource-constrained farmers will tend to invest in intensifying herd management and increasing stocking rates (e.g. purchased feed, mobile cisterns making the grazing of temporary inaccessible pastures possible during droughts). However, without rule of law, large herds may be controlled by armed groups and allied dignitaries who are able to arm themselves to protect their activities and keep military control of scarce watering points for livestock.

Non-agricultural income is generally from aid granted by government authorities or remittances from urban-based migrant or civil servant relatives. Armed groups are also using tactics to enrol young men into their trafficking activities. In addition to trans-Saharan trade, tourism had developed significantly in the Saharan regions of Niger, Mali and Mauritania, but progress is limited by the current insecurity.

Key priorities for the arid pastoral and oasis farming system are outlined in the following discussion and summarized later in Table 14.3. Thereafter, Table 14.4 also presents intervention strategies for a selection of arid pastoral and oasis farming system sites and their specific characteristics.

Population, hunger and poverty

Reduction of rural poverty is not limited to increasing agrosilvo-pastoral production and off-farm income. A fundamental condition for sustainable growth and socioeconomic development is also improved (qualitative and quantitative) access by farmers to goods and services (road and transport infrastructure, technical support services, education, health) whose supply is normally a public responsibility. Strong political will is required to make the investments needed to reduce the challenges of remoteness and isolation of oasis agro-ecosystems and increase the opportunities for their economic development.

Vulnerability to food scarcity can be reduced by anticipating and locally managing food crises, for example by storing resources or diversifying activities. Usually crises have resulted from a combination of complex phenomena, such as the increase in world prices for basic foodstuffs, a break in traditional solidarity among people, simultaneous deregulation of markets in different geographical areas, and late or inappropriate government reaction.

Table 14.2 Relative importance of household livelihood improvement strategies*

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total ag pop	—	27	73	100
Intensification	0	0.5	5	4
Diversification	1	1	2	1.5
Increased farm size	0	0	3	2
Off-farm income	3	3.5	0	1
Exit from agriculture	6	5	0	1.5

Sources: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.
* for the sub-Saharan component of the arid pastoral and oasis farming system.

Natural resources and climate

Sound technical and social management of water resources is critical for adequate oasis function. However, shortage of water resources, obsolete water management rules, abandonment of community resource management and the uncontrolled proliferation of private pumping systems threaten the sustainability of some oases. Recent change that permits private initiatives at the expense of collective ones has undermined social control of water resources and excluded some people from acquiring water access rights.

Better control of water pumping and pumping systems must be ensured. In most countries where oases occur, water pumping is controlled by laws and regulations to avoid overuse of the resource, but these are frequently violated. While law enforcement and administration need to be consolidated, local development experiences have shown that strengthening social control of water resources has much more impact on sustainable management of this resource (Ostrom 1990). Such social control has allowed the survival of oases for past centuries. Regaining a greater equity in water resource access is a prerequisite for mobilizing oasis populations towards this reconstruction (Jouve et al. 2005).

Economically unsustainable individual initiatives threaten the sustainability of some oases. The emergence of new management institutions must be facilitated so that sustainable management of resources and infrastructure can be collectively agreed and adapted to local conditions (Deygout et al. 2012; Jouve 2012). These institutions could be the new territorial governments (rural communes) set up in the context of political decentralization and democratization. However, their wide operational zone is often an obstacle to effective participation and results in very high operational costs. Therefore management structures should be anchored at the level of local oases and allow local people, especially women, to determine their own development. Examples of local, decentralized, common property resource management have been developed in Mauritania and can provide lessons in appropriate models of organizational and legal frameworks (Bonnet 2012). The proliferation of interventions by oasis-based NGOs, often initiated by highly trained individuals of local origin, shows that civil society participation is a major asset for building sustainable development policy for oases.

Significant investment is required to restore and create water management infrastructure that is more efficient and adapted to the physical environment and local management capacity. The restoration of irrigation networks, and development of micro-irrigation and mutual arrangements for operating pumping systems to support small private gardens in the periphery of old palm plantations, should be encouraged. Wadi development infrastructure can also promote groundwater recharge and leverage the significant efforts required for the establishment of a palm plantation. From this point of view, the management experiences with various water capacity thresholds developed in Chad and Niger are to be promoted (Banzhaf et al. 2012; Bender 2007).

Pastoral water management must also be integrated into the water management strategy, given the economic and agroecological roles played by animals and their products. This includes pastoral wells, water reservoirs in rangelands and secure pastoral access to wadis managed for oasis farming.

Local people's initiatives to promote woodland regeneration and control sand accumulation need to be supported. Shifting dunes that are responsible for sand accumulation in oases can be stabilized using mechanical and biological means (see second paragraph in 'Promising system management and restoration technologies' in 'System and subsystem performance' section earlier).

Energy

Access to energy is essential for sustainable development, health, social welfare, peace and security, and the fight against poverty. As in other farming systems, it is important to reduce reliance on wood energy and fossil fuel imports, and to promote electrification and gas energy through subsidy and education programmes. Renewable energy can also be a solution to the energy deficit: solar energy has a huge potential for this system and should become a major component of energy production by the 2040s in Saharan zones. Similarly, thermal energy must be explored and used. But poorly adapted policies and regulations are the main cause of the inability to exploit the enormous potential of renewable energy. The key to tapping the energy potential of sub-Saharan countries lies in opening energy markets to private sector investment. With political commitment, countries of the arid pastoral and oasis farming system could transform their remote villages, triggering a cycle of economic growth and stimulate technological innovation in critical sectors such as agriculture, livestock and food security.

Agricultural knowledge and human capital

The availability of information for smallholder farmers is critical to both the intensification and diversification of arid pastoral and oasis farming system. Both traditional and modern knowledge is necessary in the design of new ecological intensification models and increased agrosilvo-pastoral production in the various layers of oasis agricultural systems.

Apart from water, livestock is also a key element of the sustainability of arid pastoral and oasis farming system. They provide essential organic matter for soil fertility and are key economic pillars in integrated farming practices and the trans-Saharan livestock trade that oases make possible. Support to oasis farmers should focus on the improvement of integrated systems: food, productivity, value addition of manure, reducing drought effects on livestock, land management to ensure access to water, and protection against cattle theft.

The challenge for agricultural research in this farming system is to develop new models of oasis agriculture based on sustainable management of natural resources, to ensure harmonious development. This new agriculture should aim to deliver not only increased quantities produced but also ecological services rendered, the rational use of water and investment in farmer training and empowerment. The innovative character of such production systems should also help enhance the image of agricultural activity among oasis communities, including the youth who need to invest in oasis development.

The increasing isolation and the weakening of Sahelian public services to the farming system must be overcome – through improved transport, education and other services to improve human capacity. Also, the current institutional landscape includes a multitude of organizations that need to be more systematically identified and involved in development strategies to help oasis communities successfully adapt to new technological, economic and social realities. The restructuring and improved organization of stakeholders will be a decisive factor in the rejuvenation and sustainable development of oases and surrounding territories.

Basic needs of women and their families will be better met when their contribution and responsibilities are recognized, when they obtain property rights, better access to services and markets, a voice in decision-making about resources and products, and more control over income. For this purpose, a better understanding of constraints and opportunities for

the economic participation of women is needed. Priority should be given to how women can get access to services, information, education and training. Because they have been less exposed to education programmes than men in the past, both the format and content of training and information dissemination need to be targeted to women's specific needs. Putting active means, resources, technologies and inputs in the hands of women will have important consequences for addressing hunger and creating wealth in the arid pastoral and oasis farming system.

Science and technology

Maintaining high levels of productivity requires a continuous supply of organic matter – this is provided through livestock in oases, which is why mixed crop-livestock management practices are essential for the survival of oases. Research on appropriate agronomic, technical, hydraulic and economic techniques and innovations should be mobilized to assist oasis farmers and herders who manage these systems. Emphasis on variety improvement for higher yields and lower water use requirements is also needed. Infrastructure and means of preservation and processing of harvested products must be developed in order to avoid losses and realize economies of scale to achieve favourable prices on national and international markets.

Increased frequency of droughts is predicted with climate change, and improved herd resilience is an area for improvement. The use of crop residues could be significantly enhanced through grinding and nitrogen addition, as demonstrated in Nigerien research. During crises, emergency systems for supplying fodder to livestock that are managed collectively by governments or international aid tend to be heavy and untimely. In order to enhance pastoral resilience, structural livestock feed supply chains should be established. These allow higher herd stocking rates while preventing high losses during extreme weather events (Bonnet and Guibert 2012).

Almost all arable land in oasis agriculture is used, yielding a diversity of produce. Therefore, there are two main oasis development options:

- 1 intensification through more efficient technical support and easy access to means of production (inputs, improved seeds, technical equipment)
- 2 improving the quality of products and value addition. This can be done not only by promoting improved varieties and those appreciated by consumers but also by improving products' visual aspects and packaging.

However, in response to international food crises and demographic pressure, governments must also step up their support for the development of oasis zones by restoring and extending existing perimeters and increasing mobilization of available water using new proven technologies. This calls for an integrated water resource management approach that ensures both optimal and sustainable water collection, and product value-addition over time. Specific needs for water extraction, irrigation and drainage techniques adapted to oasis environments need to be planned for in relation to the growing demand and markets of Saharan urban centres.

Markets, value chains and trade

The 2012 northern Mali conflict is evidence that governments should prioritize interventions to reduce isolation of these areas and open them up through new roads to

allow marketing of agricultural production and to supply local populations with primary necessities. This opening up of the region must not only be economic but also social and political.

Once water management is improved, the regeneration of degraded palm plantations can be undertaken through the replanting of palm trees, favouring bayoud-resistant varieties and improved maintenance of palm plantations (Jouve et al. 2005). After their restoration, the economic viability of oases depends on their level of agricultural production. Given severe constraints faced by oasis systems (isolation, land and water fragmentation, high evapotranspiration), the challenge is to use a production strategy that promotes the comparative advantages and opportunities of oases. Countries such as Tunisia and Algeria have been able to enhance the production of quality dates with the 'Deglet Nour' variety and to develop their exports. But sustainable production cannot be based on monoculture of a single date variety. The wide range of fruit trees that can grow under palm trees, including apricot, fig, olive, peach, pomegranate and orange, is also an economic opportunity that deserves to be better utilized. For high altitude oases these new fruit crops are economically more promising than palm.

A condition for enhancing the value of these crops is to promote producer organizations and the acquisition of knowledge and experience for value-addition through sorting, storage and preservation, packaging, and even marketing and branding as is attempted in southern Morocco with the support of the United Nations Development Programme. A primary step to achieve these improvements is to promote the establishment of well-structured producer organizations with the aim of improving the presentation of products on the market, particularly for dates or other specific products (saffron, henna) and therefore increasing revenue and supporting more active, local economic development (Vandecandelaere 2012).

Livestock trade in the Sahel, notably the camel and small ruminant export sectors, can be supported or revitalized through improved health controls that ensure export of healthy livestock. It can also be strengthened through infrastructure development that facilitates the reception and exchange of cattle convoys on foot or by truck: development of livestock markets, creation or rehabilitation of pastoral water points, tracking markers along routes in dangerous desert zones, and engineering of crossings or fragile road sectors and crossings of wadis.

Policies and institutions

Survival of oases is largely dependent on income sources other than from agricultural products. Income from remittances sometimes takes over what used to be generated by the caravan trade. This income has so far been used mainly to meet the needs of family members who remained in the oases. But when back in their countries for retirement or as a result of the economic crisis in northern countries, some migrants invest in economic sectors such as trade, transport, agriculture and tourism. This trend should be encouraged.

The public attraction to oases due to their architectural heritage, beautiful scenery and the hospitality of local people is favourable to tourism development. Activities that have developed in Saharan zones of northern Mauritania, Burkina Faso, Mali and Niger provide relevant examples. When security conditions are met, this opportunity should be enhanced while ensuring that income generated can benefit the largest number of families and that tourism does not lead to altered quality of sites and human relations. Following the major wave of insecurity in the western Sahel, activities which used to thrive in the

Air and Nigerien Ténéré regions as well as northern Mali and Mauritania have shifted towards the Ennedi and Tibesti regions in Chad.

Apart from major commercial palm plantations mostly observed north of the Sahara, traditional oases are struggling to maintain economic viability on their own despite remittance and tourism income. As is the case for hardship areas in Europe, their future also depends on national and international solidarity. This solidarity has begun to emerge in Maghreb countries through the development of public policies favouring the creation of offices and infrastructure in oasis zones. At the international level, FAO has already recognized oases as a component of world heritage through the Globally Important Indigenous Agricultural Heritage Systems (GIAHS).

Lastly, despite their low population density, northern Sahelian desert areas are strategically critical in political and economic terms due to their abundant mining resources. They are thus entitled to public services that are well adapted and equally effective as in other parts of the country. Recent administrative decentralization must be supported with financial and human resources that permit a true recognition and legitimacy of communities in these very distinctive territories, and set up a democratic and responsible management of infrastructure and public services.

Conclusion

The arid pastoral and oasis farming system is a centre of human activity within vast Saharan, north Sahelian and southern African land expanses. They represent important geographic sites for community survival and strategic locations on trans-Saharan trade routes for the exchange of Sahelian, Saharan and north African products.

In this hyper-arid environment, oases and Saharan depressions offer access to water that sustains life and integrated agrosilvo-pastoral systems producing dates, vegetables, other products and often salt. These activity centres are not necessarily autarkic and self-reliant. Beyond production, they function to enable exchange and trade networks through major trans-Saharan routes. The wide diversity of situations derive from ecological dynamics linked to water resources as well as socioeconomic characteristics of regional trade routes which may sometimes escape the control of states and local communities.

Local agricultural production systems are certainly very limited in size compared to pastoral and agropastoral areas further south, yet the arid pastoral and oasis farming system allows for the utilization of vast expanses of semi-desert or desert land. In addition their networking has contributed to making very important trans-Saharan trade possible for centuries.

Threats to these systems should be a major concern of policymakers, given the isolation and implosion they may experience due to development of narcotics trafficking and Islamist terrorism. Other threats are related to the fragile natural environment (dune encroachment, salinization, groundwater depletion), and also to economic changes (trade, political orientations, interventions or abandonment of roads) and government weaknesses that manifest in the lack of utilities, rule of law, political control and appropriate policies for sustainable development.

For communities in these Saharan, north Sahelian and southern African regions, the challenges of sustainable development are numerous and substantial: increased agricultural production adapted to markets, protection and sustainable management of water resources, soil fertility and pastures, protection against degradation of fragile environments, improving infrastructure and linking agricultural intensification with market development.

Table 14.3 Summary of strategic interventions for the arid pastoral and oasis farming system

<i>Drivers of farming system evolution</i>	<i>Intervention</i>	<i>Implementers</i>	<i>Implications for farming system structure and function</i>
Population, hunger and poverty	Invest in improved infrastructure and increased access to services (transport, family planning, health, education, agricultural extension)	Ministries; World Food Programme; NGOs	Increased opportunities for development, wider access to off-farm income; better coordinated services to farmers
Natural resources and climate	Decentralization; empowerment of local organizations in sustainable resource management; equitable and social water management; governance of natural resource use	Ministries; NGOs, projects; communities; farmers' organizations	Increased productivity and resilience
Human capital, gender and agricultural knowledge	Improve communication infrastructure (local radios) and farmer access to agricultural knowledge; increase women's access to services, information, education and training; strengthen organization of stakeholders	Ministries; NGOs; WFP; research institutions and training	More knowledgeable farm managers; use of appropriate technologies; enhanced contribution of women to food security; enhanced community representation and capacity for local development
Energy	Improve access to energy services; open energy markets to private sector; promote renewable energy	NGOs; ministries; other organizations	Reduced poverty; economic growth; stimulation of technological innovation in agriculture, livestock and food security
Science and technology	Promote integrated market-oriented production systems; involve private sector; support labour-reducing and soil fertility management innovations; establish structural livestock feed supply chains	Farmer groups; ministries; projects	Higher profitability of new technologies and more integrated farming systems; increased pastoral resilience
Markets and trade	Promote system linkages with international markets; open markets through road construction; support market information including ICT and credit; better access to services and markets	Agribusiness; NGOs; private organizations	Wider choice and better informed production and marketing decisions therefore increased eco-efficiency
Institutions and policies	Strengthen public services; establish innovative development models and projects at regional and trans-Saharan scale; reduce barriers to cross-border agricultural trade; land tenure; farmer training; micro-credit	Ministries; NGOs; World Bank	Increased regional cooperation in development planning; lower cost and wider choice in inputs; increased farm gate prices; sustainable land management

Table 14.4 Intervention strategies according to the characteristics of selected arid pastoral and oasis sites

<i>Site</i>	<i>Physical environment and resources</i>	<i>Settlement history</i>	<i>Dominant livelihood system</i>	<i>Major system threat</i>	<i>Project experience to date in system management</i>	<i>Priority intervention strategies</i>
Manga oasis basins in Niger (Goudounaria)	Ancient dune erg with surface water table from the Chad Lake basin	Manga society historically occupied basins	Doum and date palm plantations, vegetable gardening (cabbage, banana, onion, maize, cassava, etc.); pastoralism in the oasis periphery, gum arabic and salt extraction	Sand accumulation, invasive dunes leading to the abandonment of oasis depressions; rise of saline conditions; landlocked position; low product sales linked to low commercialization capacity; permanent emigration; deterioration of public infrastructure	Dune repair work; value chain strengthening for supply and marketing; infrastructure, wells, roads	Support for local integrated management, desertification control and value chain organization; public investment in water management, health, school education and reduced isolation through road construction
Kawar Oasis (Bilma, Dirkou) in Niger	Fossil wadis of Bilma with ancient palm grove	Saharan societies; with Kanuris and Tubus	Date palm plantations, salt; important market for livestock, salt and dates on caravan route	Persisting isolation and insecurity which slows the sale of agricultural production; drying up of valleys and water salinization	Air and Ténéré resource co-management project	Opening up of the region; irrigation infrastructure restoration following recent floods; strengthening of public security in the region; support for NGOs, Tran-Saharan Road Project, Great Green Wall Project

Fira wadi in the Ouaddai in Chad	Ouaddai wadi with significant runoff and sand accumulation	Farmer-herder ethnic groups	Development of flood recession sorghum (bere bere), vegetable crops (onion, tomato, etc.)	<p>Persisting local isolation; local organization constraints for waterworks maintenance, including flood management/irrigation dikes damaged by intense floods in 2010 and 2012</p>	<p>Support for and networking of local producer organizations; management of flood thresholds, rock bunds, individual pump facilities</p>	<p>Support for local organizations and networks: improvement of roads linking villages to the regional capital; land management that better integrates mobile pastoralism; funding system for waterworks' maintenance</p>
Assaita oasis in Ethiopia	Oasis on the banks on the Awash river which splits into several parts before flowing into neighbouring lakes; these irrigate the only arable lands in this hostile environment	Afar communities of the Awash valley	Agropastoral system where the agricultural component complements and enhances transhumant livestock production; this diversified system promotes higher food security and desertification control; new industrial farms run by the state or private investors have cropped the fertile pasturelands of the Awash valley	<p>The Afar people have lost their best dry-season grazing lands; thousands of hectares carelessly put into cultivation by industrial farms (with no drainage and untimely irrigation that raises aquifer levels) have or are becoming saline, and will thus become unfit for agriculture, thereby threatening food security of local populations</p>	<p>Given constraints of the traditional Afar pastoral system, current work aims for oasis development while benefiting the communities of Afar livestock keepers (with a focus on date palm introduction)</p>	<p>Development of the system needs to support diversification, higher food security and desertification control; it should also facilitate development of socioeconomic structures that contribute to integrated rural development</p>

(continued)

Table 14.4 (continued)

Site	Physical environment and resources	Settlement history	Dominant livelihood system	Major system threat	Project experience to date in system management	Priority intervention strategies
Djibouti oases	Oases in 80 sites located along wadis	Afar groups in the North and Centre; Issa groups in the South	There are several types of oasis gardens: 1) altitude gardens with vegetables and fruit trees; 2) continental gardens with vegetables and sheep fattening; 3) dairy gardens with fodder and livestock; and 4) specialized ornamental and aromatic gardens; the northern part of the country specializes in fruit tree growing in the mountains and fodder production along the coast, while the south is more multipurpose	Small herders who have become vulnerable as a result of the desertification of pasturelands find refuge along alluvial valleys and impoverished civil servants succeed in generating sufficient income to maintain agropastoral activities by using cheap labour	Participatory planning of surface water retention works, agropastoral well infrastructure, grazing zone exclosures, income generating activities and community capacity strengthening	Oasis development is one of the national objectives; this strengthens the livestock sector (through fodder production) and contributes to vegetable production; another objective is to secure the livestock sector by expanding the collection of runoff water for herds, irrigation and regeneration of grazing lands
Adrar oasis in Mauritania	Adrar region is a plain flanked by plateaux cliffs; plateaux are intersected by valleys which sometimes form deep gorges where oases are found	Agropastoral Moorish groups including marabout tribes (Smacides) and their believers (Telanides) as well as Baratines; pastoral societies (Hassan groups and of Adrar, the Ouled Delim, Reguebats of Tell and Sahel and Gouacem)	Well-maintained and irrigated oases with date palms and rare cropping	Fallback oases for herders who have lost livestock due to the 1973 and 1984 droughts	Support for agricultural management and development	Conservation, mobilization and utilization of natural resources: water, water management facilities and equipment ; control of sand accumulation; socioeconomic infrastructure and services: opening-up of region, health services; economic agricultural production: control of livestock encroachment in palm plantations, manage palm diseases, marketing support

But sustainable development primarily depends on the security of local people and goods locally produced with high levels of know-how (Plateforme Pastorale Tchadienne 2013). Maintenance of security and development of these sparse, arid systems are possible from a technical point of view, if one considers various experiments on the northern and southern shores of the Sahara. But this presupposes that concerned governments invest in the socioeconomic development, education and health of these territories and truly recognize responsibilities for managing these systems and the resources they can generate.

Given their remoteness in desert areas, decentralization of decision-making power to local oasis communities is necessary. Their sustainable development therefore rests upon strengthening farmer capacity as well as improving and linking marketing systems to new regional channels.

As was the case historically, the development of Saharan systems still relies on the trade routes to which they are linked (four geographical meridians of the Saharan world described by Monod (1968)). Not all of the main trans-Saharan routes have become grey and uncontrolled areas like northern Mali (Choplin and Pliez 2013). The western Moorish meridian going from Morocco to Senegal through Mauritania is experiencing a true revival because of the coastal road infrastructural development that took place through agreements between national governments to facilitate and secure exchanges. Only a regional political will by Saharan states to break geographical isolation, add value in the utilization of renewable natural and mining resources, and ensure security can promote real economic development in these areas. In this context oases can become indispensable centres and relays for modern trans-Saharan economies.

Glossary

Foggaras: long, underground structures to supply water to some oases from the mountains or plateau. This ancient technique has emerged in Iran under the name ‘Qanat’.

Guelta: is a word of Arabic origin which means temporary water bodies or perennial flow without apparent source (from a spring); ponds found in the beds of wadis, often surrounded by mountains. They can be found in situations protected from sun in the mountains, as in the Ennedi and the Adrar des Iforas in Mali.

Khettara: is a drain designed to transport groundwater from the mountains to agricultural land. It usually begins near a well in the foothills of the mountains where underground water is available but cultivable soil is not. The water moves by gravity from this place through a tunnel to an oasis.

Wadi or Oued: is an Arabic term traditionally referring to a valley. In some cases, it may refer to an ephemeral riverbed that contains water only during times of heavy rain, or simply an intermittent stream.

Notes

- 1 Oases are intensively cultivated areas with access to water in desert or arid environments that are generally characterized by a large deficit between precipitations and evaporation linked to high temperatures and frequent dry winds (Lacoste 1987).
- 2 Oasis depressions are specific geomorphological units of spatially limited area (up to a few hectares) found in inter-dune depressions with clayish soils where oases are found.
- 3 salt that comes to the soil surface through capillary action. It is collected, at least partially separated from its muddy base, evaporated, and transported in long blocks on camel back.

References

- Banzhaf M., Maikorema Z., Djimrao I., 2012. Expériences du Niger dans Aménagement et gestion des bassins versants. Etude de cas, in Deygout et al. *Systèmes de production durables en zones sèches, quels enjeux pour la coopération au développement?* AFD, IRAM.
- Bender H., 2007. GTZ – Projet EON Tchad. Aménagement des bas-fonds à l'aide de seuils d'épandages. Sécurisation des bases de vie dans les zones des réfugiés à l'Est du Tchad en coopération avec le Programme de développement décentralisé d'Assoungba – Biltine – Ouara, PRODABO.
- Bonnet B., 2012. Analyse de quelques expériences de gestion locale des ressources naturelles communes au Sahel. In *La grande muraille verte. Capitalisation des recherches et valorisation des savoirs locaux*. Ss la coordination Pr. A. Dia, Dr R. Duponnois, IRD, pp. 395–411.
- Bonnet B., Guibert B., 2012. Vulnérabilités et efforts d'adaptation des familles de pasteurs face aux crises récurrentes. Enseignements tirés de l'analyse de l'activité pastorale dans les trajectoires familiales, s.l., ECLIS-ANR-IRAM.
- Choplin A., Pliez O., 2013. *Un Sahara, des Sahara-s. Lumières sur un espace déclaré 'zone grise'*. Université Paris-Est.
- Deygout P., Tréboux M., Bonnet B., 2012. *Systèmes de production durables en zones sèches, quels enjeux pour la coopération au développement?* Philippe Deygout, Marion Tréboux avec l'appui de Bernard Bonnet, MEE Direction générale de la mondialisation, du développement et du partenariat, AFD, IRAM. Rapport présenté au Forum Mondial de l'Eau et à Rio +20.
- Dollé V., 1982. La D'Mane: brebis des palmeraies, in *Productions pastorales et sociétés*, N 10, Maison des Sciences et de l'Homme Editeur.
- Dollé V., 1985. *Agriculture mauritanienne et recherche*. DSA-CIRAD.
- FAOSTAT (undated) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- Godard V., Dollé V., Vayssières J-F., 1990. *Un diagnostic rapide pour l'agriculture oasienne. Mise au point méthodologique pour l'utilisation de données satellitaires SPOT dans la région de l'Assaba mauritanien*. Options méditerranéennes, série A/n 11, 1990 – Les systèmes agricoles oasiens, pp. 91–102.
- Ichaou A., Guibert B., 2009. *De la dune fixée à la cuvette retrouvée. L'exemple du projet d'appui à la gestion des ressources naturelles au Niger*. Karkara-IRAM.
- Institut National de la Statistique (INS) et Macro International Inc, 2007. *Enquête Démographique et de Santé et à Indicateurs Multiples du Niger 2006*. Calverton, MD: INS et Macro International Inc.
- Jouve P., 2012. Les oasis du Maghreb, des agro-écosystèmes de plus en plus menacés. Comment renforcer leur durabilité? *Courrier de l'environnement de l'INRA* no. 62.
- Jouve P., Raymond L., Hassan M., 2005. Du déclin à la régénération des oasis de la région de Tata (Maroc). *Symposium international pour le développement agricole des systèmes oasiens*. 7–10 March 2005, Erfoud Maroc
- Lacoste Y., 1987. *Encyclopedia universalis* p. 13. Oasis.
- Mendelsohn J., 2006. *Farming systems in Namibia*. Namibia National Farmers Union, Ambassade de France en Namibie.
- Monod T., 1968. Les bases d'une division géographique du monde saharien. *Bulletin de l'IFAN*, 30, B (1), Dakar, pp. 269–288.
- Ostrom E., 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press.
- Penot M., Martinez Sanchez A.F., Apriyana Y., 2002. Les systèmes de production des jardins de Tabelot, in *Etude des jardins de Tabelot et des Bagzan dans la Massif de l'Air, contribution au développement local dans le Nord Niger*. CNEARC, ONG TILALT, pp. 16–30.
- Pini G., Tarchiani V., 2007a. *Les systèmes de production agro-sylvo-pastoraux du Niger : description et analyse*. Centre polytechnique de Turin.
- Pini G., Tarchiani V., 2007b. *Les systèmes de production agro-sylvo-pastoraux du Niger: La caractérisation agro-écologique*. Turin: Centro Città del Terzo Mondo. Politecnico di Torino.
- Plateforme Pastorale Tchadienne., 2013. *Déclaration de N'Djaména, Élevage pastoral, une contribution au développement et à la sécurité des espaces saharo-sahéliens*. Colloque Régional, Conférence Ministérielle 27–29 May. République du Tchad, AFD, UE, CSAO, FIDA, IUCN, DDC.

- Retaille., 1986. Les oasis dans une géographie méridienne Sahara-Sahel. *Cahiers géographiques de Rouen*, n 26.
- Riou., 1988. Bioclimatologie des oasis. *Séminaire sur les systèmes agricoles oasiens*. Tozeur, Tunisie, 19–21 November.
- Schmitz J., 2000. L'islam en Afrique de l'Ouest: les méridiens et les parallèles. *Autrepart*, vol. 16, pp. 117–137.
- Toutain G., Dollé V., Ferry M., 1989. Situation des systèmes oasiens en régions chaudes. *Communication présentée au séminaire sur "Les systèmes agricoles oasiens"*, Tozeur, Tunisia, 19–21 November 1988. Options méditerranéennes, série A/n 11, 1990 – Les systèmes agricoles oasiens, pp. 7–18.
- Vandecandelaere E., 2012. Safran de Taliouine AOP: la mise en place d'une appellation d'origine pour promouvoir une approche durable dans les montagnes sèches de l'Anti-Atlas au Maroc. Etude de cas, in Deygout et al. *Systèmes de production durables en zones sèches, quels enjeux pour la coopération au développement?* AFD, IRAM.

15 Perennial mixed and island farming systems

Exploiting synergies for maximum system productivity

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Key messages

- These two small and unusual farming systems are located on the periphery of the African continent yet have interesting lessons for the development trajectories of the larger mainstream African farming systems.
- The perennial mixed farming system is based on commercial trees (olives, fruit or forestry), vines or sugarcane augmented by cereals, pulses and livestock. The island farming system blends food crops, horticulture and some perennials in diverse mixtures depending on the particular environment of each island.
- The key drivers of rapid evolution of both systems are demography and climatic and market development and variability.
- Strategic interventions should focus on market access and value chains, resource management and expanded research on production and processing, taking into account location specificity.
- In relation to lessons for other African farming systems, attention could be given to the formal and informal institutions for market intermediation; adaptive mechanisms for climate variability; well organized and strong industry bodies which represent growers in policy debates and export negotiations; and the importance of ecological and economic niches in farming system development.

Summary

Two farming systems are analysed in this chapter: the perennial mixed farming system found in the southern and northern extremes of the African continent, and the island farming system found in the Indian and Atlantic Oceans. The perennial mixed farming system is distinguished from other African systems by the Mediterranean climate and access to relatively good domestic and export markets. The system comprises three subsystems: the sugarcane and production forest subsystem in southern Africa; the deciduous fruit and wine grape subsystem which is concentrated in the Western Cape region of South Africa; and the north African rainfed mixed subsystem, found especially in Maghreb countries. The two subsystems in southern Africa have advanced linkages to public research, industry and the private sector – with consequent benefits for innovation, productivity and international competitiveness, while maintaining local food crop

and livestock production. One of them, the sugarcane-forest subsystem exhibits strong dualism with small and large commercial farms side-by-side. The north African rainfed mixed farming subsystem features integrated, crop-livestock production with pockets of commercial production of perennials, notably olives and temperate fruit, with relatively good domestic market access and selected export market access to the European Union. Compared with other African farming systems, the perennial mixed farming system is semi-mechanized and exhibits high capital and labour productivities. Because of excellent access to finance, new technology, management and other agricultural services, the southern African subsystems are resilient in the medium to long term, but vulnerable to international market fluctuations and currency exchange rate shifts in the short term. The northern African rainfed mixed farming subsystem currently has medium access to markets, finance, technology and services, but these are expected to strengthen in the 2020s.

The island farming system is also a mixed system, often with some perennials, which supports modest populations across diverse ecologies in half a dozen small islands in the Indian and Atlantic Oceans, excluding Madagascar which is analysed in Chapters 3, 4, 9 and 11, this volume. In addition to fishing, the island system includes a wide variety of tree crops, fruit, vegetables and livestock, because of diverse edaphic-climatic and market conditions. In some islands (e.g. Mauritius), farmers often benefit from the demand from resorts for high-value horticulture and other produce. In the middle-income islands, many farmers are expected to exit agriculture in the 2020s and the remaining farmers to intensify and diversify to supply local and export markets. In the low-income islands, yield gaps are large and farmers would benefit from intensification through better input use efficiency (especially water use efficiency) during the 2020s.

Introduction

This chapter analyses two geographically dispersed and unusual mixed farming systems. The perennial mixed farming system is found in the southern and northern extremes of the African continent. The island farming system is located on the scatter of small off-shore islands associated with the African continent. These subsystems are unique farming and food systems with some lessons for African farming systems development more generally.

Perennial mixed farming system

Overview of the farming system and subsystems

The perennial mixed farming system described in this chapter is found in South Africa, Swaziland and north Africa. In the Western Cape Province, South Africa and in north Africa the system occurs in coastal areas with a Mediterranean climate and moderate rainfall. In Swaziland and in KwaZulu Natal, South Africa, the climate is strongly sub-humid with warm season (summer) rainfall. Agroecological conditions are varied, but the farming system has better access to agricultural services including input and produce markets, technologies and information than most other African farming systems.

In this farming system, farmers produce fruit, wine grapes, table grapes, sugarcane, forest timber products, cereals and niche crops suited to the Mediterranean climate and available markets, along with small and large ruminants. Agroecological potential and economic considerations, notably access to agricultural services, influence the choice of crops and livestock and the extent of diversification in the farming system.

The perennial mixed farming system comprises three subsystems: the sugarcane and production forest (in short, sugarcane-forest) subsystem in southern Africa; the deciduous fruit and wine grape (fruit-grape) subsystem, which is concentrated in the south-west of South Africa; and the north African rainfed mixed subsystem, found in Maghreb countries.

Table 15.1 provides estimates of basic data and characteristics of the farming system, distinguishing the two southern subsystems from the northern subsystem. The geographic extent of the subsystems is shown in Figure 15.1. The southern sugarcane-forest and the fruit-grape subsystems have developed over centuries in coastal and hinterland areas extending over about 20 million ha. Soils are of moderate or low fertility and about 20 per cent of the system occurs in steep, dissected terrain. Precipitation reduces with distance from the coast, and the average length of growing season is 165 days. High value crops grown on more than two-thirds of the cultivated land are irrigated.

Figure 15.1 Map of the mixed perennial farming system and its three subsystems.

Source: GAEZ FAO/IIASA, FAOSTAT), Harvest Choice and expert opinion.

In 2015, the two southern subsystems jointly supported 13.8 million people, of whom 1.8 million could be considered agricultural (including labourers). Because of advanced urbanization, the agricultural population represents only 13 per cent of the total population and farmers benefit from well-developed infrastructure and good access to services and markets. Some 22 per cent of the rural population is poor, living on less than US\$1.99 per day. Livestock densities are typical for Africa. Length of growing period varies in the two subsystems, with an average of 188 and a core range of 150–240 growing days in the sugarcane–forest subsystem, and an average of 123 and a core range of 60–180 growing days in the fruit–grape subsystem (see LGP data for the two combined subsystems in Table 15.1).

The southern sugarcane–forest subsystem comprises a mixture of smallholder farms and large privately owned commercial farms and plantations. In contrast, due to high technological, knowledge and capital inputs, typical smallholders are not common in the fruit–grape subsystem. There are various ‘equity sharing’ farm businesses where farm labourers share in the ownership and profit of the farms. The agricultural population density is typical for Africa, but agricultural population density per cultivated area is the lowest in sub-Saharan Africa. Assuming an average farm household size of 5.5 members, the average farm size is 8.7 ha, much larger than the African average.

The northern rainfed subsystem has a similar land area but more than twice the total population (36 million) and agricultural population (10 million) than the southern

Table 15.1 Basic system data (2015): perennial mixed farming system

Item	Subsystems, southern Africa	Subsystem, north Africa
Total human population (million)	14	36
Agricultural population (million)	1.8	10
Total area (million ha)	20	17
Cultivated area (million ha; % of total area)	2.8; 14	10; 56
Irrigated area (million ha; % of cultivated area)	2.0; 7.1	0.3; 3
Total livestock population (million TLU)	2.3	3.8
Major agroecological zone	Subtropical/tropical warm semi-arid	Subtropical warm subhumid
Length of growing period (average, days; core range, days)	165; 120–240	207; 180–240
Access to services	high	high
Distance to 50k market (average, hr; core range, hr)	3.8; 1–6	2.7; 1–6
Agricultural population density (persons/total area; persons/cultivated area)	0.1; 0.6	0.6; 1.1
Livestock density (TLU/total area; TLU/cultivated area)	0.1; 0.8	0.2; 0.4
Standard farm and herd size (cultivated area/ household; TLU/household)	8.7; 7.1	5.2; 2.1
Extreme poverty (% of rural population)	22	Low–medium

Source: Refer to Table 2.4.

Note: The climate in both the south African fruit–grape (mostly subtropical warm semi-arid) and northern African rainfed perennial mixed (mostly subtropical warm subhumid) subsystems is often referred to as Mediterranean climate.

subsystems. With an average length of growing season of 207 days, most farmers engage in rainfed crop and livestock production. About 10 million ha are cultivated but, in contrast to the southern subsystems, little is irrigated. The typical farm household cultivates about 5 ha and manages a small flock of sheep and goats.

Sugarcane and production forest subsystem

The sugarcane-forest subsystem benefits from adequate rainfall and mild temperatures experienced in the South Africa and Swaziland region. The forestry plantations are established on the steep slopes, while sugarcane is planted on the better quality land with heavy fertile soils (Figure 15.2). As noted earlier, the subsystem is characterized by a mix of large, commercial private farms and numerous smallholder farms. Maize and livestock production is scattered across the subsystem, particularly on the smallholder farms.

Sugarcane and forest plantations tend to co-exist because of their complementarity. Sugarcane has a 3- to 4-year cycle, whereas trees have long rotations, in this case from 8 to 30 years. In coastal areas, sugarcane tends to be planted under rainfed conditions and takes advantage of high levels of humidity and fog. Of the 430,000 ha under sugarcane, about two-thirds is grown within 30 km of the coast and 17 per cent in the high rainfall areas of KwaZulu-Natal. Sugarcane is grown under irrigation in low altitude areas of Pongola, Mpumalanga and Swaziland.

The 1.5 million ha under forest plantations are mainly pines and other softwoods, as well as *Eucalyptus spp.* and wattle (*Acacia mearnsii*). In terms of ownership, smallholder farmers and other private farmers own some 21 per cent of the forest plantations. The rest of the forestry land is owned by government (30 per cent) or private sector companies

Figure 15.2 Sugarcane fields at different development stages with black wattle and pine plantations in the background in the Wartburg areas of KwaZulu-Natal, South Africa.

Source: Maxwell Mudhara.

(49 per cent). To maximize their profitability on the generally hilly farms, smallholder farmers tend to take advantage of the varying growing conditions by having combinations of sugarcane and forest plantations, complemented by other agricultural enterprises such as maize and livestock. These combinations of smallholder enterprises take advantage of agroecological niche areas and tend to be labour-intensive (compared with the commercial operations on large farms). The escalation in labour costs has seen large producers shifting from manual to mechanical harvesting of both sugarcane and trees.

Some 95 per cent of the sugarcane growers are small scale and produce about 9 per cent of the total sugar crop and own 7 per cent of the land planted to sugarcane. Smallholder farms typically comprise a family of five to seven members. Despite their low levels of production, labour is hired when required, usually during planting and weeding. External service providers are hired for harvesting and transporting the sugarcane or trees from plantations.

In South Africa, the sugar industry makes an important contribution to the national economy, given its agricultural and industrial investments, foreign exchange earnings, high employment, and linkages with major suppliers, support industries and customers. Currently it generates an estimated annual average income of US\$66 million. Forest resources also play a major role in poverty alleviation through job creation, economic growth, supply of basic needs and, because of flexibility in harvesting age, acts as a safety net against inter-seasonal climatic variation, including employment generated at the local community level.

Deciduous fruit and wine grape farming subsystem

The fruit-grape subsystem is located in the southern part of the Western Cape region of South Africa. Table grapes, pome (apples and pears) and stone fruit (peaches, nectarines,

Figure 15.3 Aerial view of deciduous fruit orchards in the Koue Bokkeveld area of Ceres district, South Africa.

Source: Pieter du Toit.

plums, prunes and apricots) are the three categories of deciduous fruits produced in this subsystem (Figure 15.3). Some citrus plantings are also found in this subsystem. Two pockets of wheat-sheep-canola-alfalfa mixed farming are also located in the southern Western Cape (described later). The deciduous fruit and wine grape farming subsystem has a mild Mediterranean climate with cool, wet winters and warm, dry, windy summers. The coast is a few degrees cooler than the inland regions and tends to be windier. Pome fruit needs cold winters and is produced in the same subsystem as stone fruit. The different soil types, terrain, topography and climatic conditions create opportunities for specialization. Some farms in this region practise mixed farming incorporating wheat, sheep, canola and alfalfa.

Deciduous fruit-producing farms cover more than 50,000 ha, predominantly within this subsystem in the southern provinces. Farms vary in size and enterprise composition. The deciduous fruits and grapes are mainly grown on nearly 1,800 commercial farms (Hortgro 2015). Twelve per cent of the grower units are larger than 100 ha, while 67 per cent of the pome grower units are less than 40 ha (Kotze 2013). Of the stone fruit-growing units, 16 per cent are larger than 30 ha representing 50 per cent of the area under stone fruit, whereas 62 per cent of the stone fruit grower units are less than 15 ha per unit and represent 22 per cent of the area under stone fruit (Kotze 2013). Ownership of commercial fruit farms is mainly single proprietors and private companies (as is the case in the sugarcane-forest subsystem). Deciduous fruit farms are capital and labour intensive, employing approximately the equivalent of 60,000 permanent labourers. Deciduous fruit orchards are irrigated, usually drip and/or micro-aspiration and are irrigated regularly.

Dry and table grapes are grown on about 27,000 ha by about 700 producers (Hortgro 2015). The area is split about 55:45 between white and red wine grape cultivars, although the ratio differs between producing regions. According to SAWIS (2013), the four main cultivars planted in South Africa are Chenin Blanc (18 per cent), Cabernet Sauvignon (12 per cent), Colombar (12 per cent) and Shiraz (10 per cent). Choice of cultivar is influenced by the terrain, market and price expectations. A wide range of wine styles is across the subsystem. Some farms are specialized grape growers, but others are diversified units (with grapes usually grown in combination with stone fruit and/or citrus). Wine grape production is labour intensive – the equivalent of approximately 50,000 labourers are employed by the industry (Hortgro 2015). The typical number of permanent labourers per farm can vary between 15 and 40 and the corresponding number of seasonal labourers between 60 and 200.

Grape production requires a high level of investment in vineyards. Except for one dry-land wine producing region, drip irrigation is the main irrigation practice, as well as some micro-, sprinkler and flood irrigation (Figure 15.4). Farmers use their own machinery (hired machinery and contractors are the exception), except for some specialized activities such as soil preparation. Pruning is done manually, while harvesting is semi-mechanized. The average time to full bearing after planting new vines is five years. A relatively high proportion of white grape vineyards are older than 25 years (SAWIS 2013).

Within the deciduous fruit and wine grape subsystem there are inclusions of commercial wheat-sheep-canola-alfalfa mixed farming, occurring in Western Cape with a medium season length of around six months. Legumes (typically alfalfa and medics) are grown in rotation with wheat and other cash crops such as canola, barley and oats and complemented by mutton sheep production. The mixed farming areas have a relatively small agricultural population (around 0.2 million and expanding slowly), comprising

Figure 15.4 Wine grape vineyard under drip irrigation in Stellenbosch district, South Africa.

Source: Elona Hesseling.

wealthy commercial farmers. The subsystem serves as the food basket as well as a major employer and the driver of agricultural growth and regional food security in the southern Western Cape.

Rainfed mixed farming subsystem, north Africa

The rainfed subsystem is found in the coastal and inland areas with moderate rainfall, extending from Morocco to Tunisia. This subsystem is moister and cooler than the southern subsystems and is characterized by winter cereals (e.g. wheat, barley) and pulses (e.g. chickpeas, lentils, medics), olives, fruit (e.g. grapes, melons) and livestock (e.g. cattle, sheep and goats). The integrated food crop and livestock enterprises have been the mainstay of livelihoods for 2,000 years. Recently, in common with the southern, perennial mixed subsystems, the rainfed mixed subsystem has pockets of commercial perennial crop production (Figure 15.5). Its proximity to the European market has encouraged cash crop enterprises (e.g. olives, fruit, melons and grapes), albeit not as well developed as those in the southern subsystems.

Livestock play an important role in the subsystem and depend on communal grazing and crop residues. Although the subsystem is principally rainfed, an increasing area receives irrigation: supplementary winter irrigation on wheat and full irrigation on summer cash crops, alongside the pockets of irrigated high value crops including fruit. Poverty among the agricultural population of 10 million is low-moderate and is alleviated by extensive seasonal labour migration.

Figure 15.5 Traditional medium-density olive-based agroecosystem in Agourai, Meknès Province in Morocco with prevalence of the Moroccan Picholine local variety. Orchards are seasonally open to grazing herds and associated with annual crops (legumes or cereals) in low density.

Source: Mohammed Ater.

Trends and drivers of change in the perennial mixed farming system

Population, hunger and poverty

The three subsystems face rapidly growing populations, yet provide substantial employment and are the leading source of livelihoods for the local residents. Poverty and hunger are low to moderate both in the northern rainfed and southern sugarcane-forest and fruit-grape subsystems. Household food security is, in general, adequate through production or purchase – although malnutrition is a growing concern.

In the southern sugar-forest and fruit-grape subsystems, the sugar industry provides approximately 430,000 direct and indirect jobs in addition to the 29,130 cane growers. Overall, approximately 1 million people depend on the sugar industry for a living. The participation of smallholder farmers in sugarcane production is increasing. Plantation forestry is also an important sector because it provides job opportunities and raw material for primary processing industries. In 2007, the plantation sector employed 630,000 people. Another 1.7 million were dependants of the people employed in the forest sector (DAFF 2012).

Deciduous fruit and grape production are also labour intensive, employing the equivalent of 110,000 permanent workers (Figure 15.6). With the gradual increase in

Figure 15.6 Harvesting of apples in the Elgin district, South Africa.

Source: Gerrit van der Merwe.

mechanization, total employment is reducing slowly. Together, these permanent or casual labourers are accompanied by about 433,000 dependants (Hortgro 2015).

In the northern rainfed subsystem, population pressure constrains average farm size to about 5.2 ha and causes considerable emigration to cities and overseas destinations. The gradual spread of mechanization is slowly reducing labour requirements for production and transport of product to market. In future decades, non-farm and overseas employment is expected to increase and therefore population pressure could begin to decrease.

Naturally, farm employment patterns of the future will be influenced by the ratio between the cost of labour and capital (e.g. machinery), which will contribute to shaping the perennial mixed farming system and the labour intensity. Labour intensity of production and processing will also be reduced by the expected increase in wage rates with growth of the national economy. Moreover, as wages increase the incidence of poverty and food insecurity should decrease provided surplus labour is drawn into other employment.

Natural resources and climate

Sugarcane, deciduous fruit and wine grape production are dependent on irrigation water, and in future the share of available water to agriculture is expected to decline as domestic and industrial demands increase. Climate change is also expected to have an effect on rainfall and temperatures. Thus the importance of optimal irrigation efficiency is expected to increase over time with improved water management and monitoring technologies. Conversely, sugarcane grown under rainfed conditions is particularly vulnerable to climate change, which is likely to lead to an expansion of supplementary irrigation.

There are some signs of soil fertility decline over much of the system. Mineral fertilizers provide a partial solution, but there is good evidence of increasing soil acidity where there has been prolonged use of inorganic fertilizers. Climate change and the associated progressive increase in temperatures may have less effect on cool season productivity, which is the dominant feature of the southern subsystems.

In contrast to most African farming systems, farming has been practised in much of the northern rainfed mixed subsystem for at least two millennia. Consequently, water and wind erosion have been common and now most soils are depleted of carbon and nutrients. The threat from climate change is striking, and the region is rated as one of the hotspots where precipitation is projected to decrease markedly – like south-western Australia where climate-adaptation cropping practices have been developed.

New plantations have been established in Eastern Cape and KwaZulu-Natal provinces because of the perceived potential for forestry. Conservative estimates for potentially available land for new afforestation in the Eastern Cape vary between 100,000 and 130,000 ha, excluding the possibility of converting the estimated 18,000 ha of invasive black wattle regrowth into commercial forestry plantations. These new afforestation sources have the potential to produce an extra 242,000 tonnes of timber, create about 41,000 jobs at plantation level (and an additional 700 jobs in processing) and contribute US\$61 million to GDP.

Energy requirements

In addition to household energy needs of smallholders in the southern subsystems, the modernization of production and processing will require considerable additional energy in the future, for example irrigation and post-harvest handling and storage. In line with this increase in energy intensity, there will be pressures for increasing energy efficiency as prices rise in the long term. There may be opportunities for improved use of biomass and residues for the generation of power.

Two of the countries of the rainfed mixed subsystem have developed oil and gas reserves and domestic fuel prices are very low, encouraging mechanization and transportation solutions.

Knowledge and capacity building

Both southern sugarcane-forest and fruit-grape subsystems produce major products which are driven by strong commercial and market factors, and production, processing and marketing are relatively knowledge intensive. It is expected that smallholders and gender equity will receive increasing attention in the coming decades, through education, training, access to resources and markets and greater integration with other sectors of the economy.

The northern rainfed subsystem also has a relatively knowledgeable farm population, although historically not so well connected to markets and research. The connectivity could change with new disruptive technologies such as smart phones.

Science and technology

South Africa is a world leader in the technology and sustainable management of plantation forests and is home to several world-class pulp and paper companies. As such, the country has a competitive pulp and paper production and manufacturing base. The Institute for Commercial Forestry Research serves the subsystem with improved eucalyptus and wattle cultivars and forest management solutions, and scans the horizon for substitute products. In relation to the post-harvest stage, companies improve the manufacturing processes.

The South African Sugar Association has many programmes that benefit both established and new entrants to the subsector. The South African Sugarcane Research Institute produces cultivars to increase sugarcane sucrose yields, pests and diseases control measures and improved crop management practices. Yield on irrigated sugarcane plantations can be as high as 80 t/ha, but smallholder farmers on dryland can have large yield gaps with yields as low as 20 t/ha. Therefore, there are vast opportunities to improve profitability of smallholder farmers by improving cane and sugar yields.

About 15 per cent of the perennial mixed zone is cultivated to sorghum, maize, common bean (*Phaseolus vulgaris*) and soybeans, which are among the best adapted rainfed food crops in this subsystem. The wheat-sheep-canola-alfalfa mixed farming optimizes wheat (and other annual crop) production on the fertile soils of the southern Western Cape over the cool growing season. Field technology plays a major role in maintaining and increasing production efficiency and livelihoods. Overall, long-term agricultural growth prospects are very good.

The northern subsystem has had moderate support in productivity innovations and natural resource management practices, yet yield gaps for food crops remain high. There is scope for increased crop-livestock integration, which would involve fodder crops in the rotations. It is expected that technologies in water and nutrient management, production and processing will be developed substantially by the public and private sectors in response to market opportunities and climate change stress during the coming decades.

Trade and markets

Export markets are crucial to the economy of the two southern sugarcane-forest and fruit-grape subsystems and important for the future of the northern rainfed subsystem – to a greater degree than all other African farming systems except for the tree crop farming system. For the southern subsystems, economic performance is underpinned by the existence of well-organized industries and well-developed value chains. In the case of the forest industry, the value chain can be classified into three main stages: plantation forestry, primary processing industry and secondary processing industry. Plantation forestry is the main supplier of raw material to processing industries which produce sawn timber, pulp, panels, mining timber, poles and chips. Although international markets are competitive, it is generally considered that medium-term demand for quality products is strong, so the well-organized forest industry is in a strong position to respond to changing product demand. The sugar industry is also well organized and faces stiff international competition, yet is also likely to survive.

Similarly, the largest share of apple, pear, plum and table grape production is exported. Cultivar choice and the ratio between red and white wine grape cultivars will influence the quantity and composition of export wine to the international market, which is becoming very competitive with new entrants to the market, such as Argentina producing large volumes. The cost-price squeeze in wine grape production has encouraged some farmers to diversify into small independent wine cellars and/or provide tourist services such as accommodation and restaurants. As with the forest and sugar sector, the fruit-grape subsystem will focus on quality, value-added products and diversification to new markets.

The northern rainfed subsystem has the advantage of seasonal access to the European markets for horticulture, as well as negotiated access for olive oil. Quality considerations will grow in importance over time and so, most likely, will certification requirements. With a greater proportion of produce flowing to domestic markets which are strengthening with national economic growth, the subsystem is in a strong position to weather volatility in export markets to Europe.

Policies and institutions

Policies and regulations have framed the development of the subsystems and will shape their future directions. The investment in sugar mills within an economic distance of large producing areas has facilitated industry growth. The creation of an industry fund to finance cane development provides finance where needed to growers. In addition, milling companies support sugarcane producers in their efforts to develop additional cane supplies. The state is providing infrastructure and services such as extension to support the sector, as are the cane-growing communities and organizations, including training to allow for effective participation by smallholder farmers. The key to the growth of the sugar sector is the existence of strong grower and miller institutions that provide the necessary support to allow production, marketing and milling of sugar. In the case of the forest industry, regulations to reduce the threat of veld fires would be an important policy area in coming years.

Fruit production systems have to fulfil specific national and international food safety and environmental legislation and regulations, as well as standards set by various local and international retailers. Wine grape farmers are encouraged to participate in the voluntary environmental sustainability scheme, the Integrated Production of Wine, which forms part of Sustainable Wine South Africa that underpins the commitment to sustainable, eco-friendly production. The Wine Industry Ethical Trade Association was established to improve the working conditions of workers in the wine value chain.

The northern rainfed subsystem has benefited from public subsidy programmes, often intended to increase production. There is potential for increased provision of food to larger cities, and linkage with regional and global supply chains for horticulture. Similarly, linkages to regional and global markets for animal products holds promise for future increased trade. There will be domestic and international market pressure for improved quality, food standards and food safety.

System and subsystem performance

Sugarcane and production forest plantation subsystem

A number of factors affect the performance of smallholder farmers in the sugarcane-forest subsystem. In general, the commercial elements of production and processing, especially

sugarcane and forest plantations, have high productivity. Conversely, smallholder food crop production has low to moderate yields. Nevertheless, because of the employment opportunities, rural poverty and hunger are low. The forestry component, which can operate independently of the sugarcane, has been affected adversely by veld fires, legislation which removed forestry from riparian zones and wetlands, and a decrease in new investments in areas where there are pending land claims. The larger industry players involved in the value chain have arranged some vertical integration. However, this means smaller players experience problems in securing supplies and creates barriers to entry for other companies in downstream processing industries.

Climate change will require adaptation and could have an adverse effect on system productivity. While research is underway on the effects of climate change on sugarcane and forests and management responses, the effects on productivity and profitability are uncertain. For example, while traditional commercial forestry in the subsystem is susceptible to reduced rainfall, Warburton and Schulze (2006) suggest that forestry hybrids will be more robust to climate change. In the drier parts, the expansion of production will depend on increased water storage. The excellent export infrastructure, world-renowned agricultural and industrial research platforms and efficient organization of the South African sugar industry have been and are likely to continue to be key drivers of good performance.

Deciduous fruit and wine grape subsystem

The profitability of the various fruit and grape crops depends on exchange rates and the respective markets where the produce is sold. Presently the exchange rate in key markets favours table grapes, plums, pears and apples, but this could evolve in the coming years.

The productivity of the grape and fruit farms is generally high (Figure 15.7). The yield of fruit varies depending on the type and cultivar and, together with fruit quality, has a

Figure 15.7 Young trees bearing Golden Delicious apples in the Koue Bokkeveld area of the Ceres district, South Africa.

Source: Gerrit van der Merwe.

direct effect on the profitability of fruit production systems. There are high establishment costs for orchards and the first full bearing of orchards is only reached after several years (typically two to seven years).

The average yields per hectare for wine grapes vary widely between the different producing regions and also between the red and white cultivars. The producer price also varies widely between cultivars, location (origin) of production, wine grape processing facility and the corresponding end product. Labour is an important cost in the production of wine grapes, yet the most profitable producers have lower labour costs and higher mechanization costs (van Wyk and van Niekerk 2013). Currently, the average producers are caught in a typical cost-price squeeze, which is leading to low levels of vineyard replacement over time.

Rainfed mixed subsystem, north Africa

While household food security and incomes have risen during the past decades, food and horticultural productivities are relatively low, as well as those of livestock. Lack of knowledge of good farm management practices has been one of the constraints to wider adoption of micro-irrigation and improved fallow and farming methods. The prospects for increased productivity and returns to land, water and labour resources are positive but modest – as the International Center for Agricultural Research in the Dry Areas has demonstrated.

Strategic priorities for the perennial mixed farming system

Strategic interventions for the development of the farming system should be informed by the opportunities open to farm households and their preferred strategies. Table 15.2 illustrates the five household strategies for poverty escape or income growth, namely intensification of existing enterprises, diversification to incorporate new crops or livestock, growth of the farm or herd, increased off-farm income or exit from agriculture. The current estimates of the relative importance of household strategies for the 2015–2025 period, based on expert judgements, are contrasted with estimates made for the earlier 2000–2015 period.

For the perennial mixed farming system, the estimates in Table 15.2 suggest that poor households have less opportunity to increase farm size now than at the turn of the century,

Table 15.2 Relative importance of household livelihood improvement strategies

<i>Poverty escape strategy</i>	<i>Extremely poor (2000)*</i>	<i>Extremely poor (2015) southern Africa</i>	<i>Extremely poor (2015) north Africa</i>	<i>Less poor (2015)</i>	<i>Large companies (2015)</i>
Intensification	2.5	3.0	2.0	2.5	4.0
Diversification	3.0	3.0	2.5	3.5	3.0
Increased farm size	2.0	1.5	1.0	2.5	2.0
Off-farm income	1.5	1.5	2.5	1.0	0
Exit from agriculture	1.0	1.0	2.0	0.5	1.0

* Estimates for 2000 refer to the perennial mixed farming system in southern Africa only.

Source: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

while the better-off households have some opportunity to grow farm size. Intensification represents an important growth strategy for all categories of households, and diversification especially for the small to medium (non-poor) households. Continued exit from agriculture is relevant to all farm household types.

Intensification and diversification, both driven by markets and technologies, remain important in southern Africa for all classes, especially the larger agrarian companies and plantations. For escape from poverty, intensification (e.g. increased yields) has increased slightly in importance since 2000, but diversification (generally to high value crops and animals) remains an important strategy. In north Africa, increased off-farm income is the most important poverty escape pathway, for example through work in capital cities or industrial developments, or in Egypt, Saudi Arabia or the Gulf. Off-farm work is complemented by exit from agriculture (generally within country), which is a successful strategy where sufficient employment opportunities are available.

Given the expected household strategies for the 2020s, the following sections indicate priority strategic interventions for sustained and accelerated growth of each of the three subsystems. These suggestions are not intended to be comprehensive or ranked in order of importance, but are indicative of the types of interventions which have emerged from the farming system analysis.

Sugarcane and forest plantation mixed farming subsystem, southern Africa

- Increase supply of raw materials (pulp and timber) to support increased export of forest products. The availability of pulp can be maintained or increased by increasing the afforested area, and rehabilitating and improving management of the existing forestry. Encourage area expansion also for the supply of timber in the short to medium term.
- Develop financial assistance mechanisms to ensure the long payback period required for investments in long rotation softwood does not discourage smallholder farmers from investing.
- Engage positively with smallholder communities with communal land suitable for forestry, noting that the bulk of the land for potential new afforestation is located on communally owned land or in some areas where there are land claims and pending tenure issues. Thus, the realization of this potential depends on clarification of land rights and the readiness of smallholder farming communities to consider plantation forestry.
- Simplify the licensing process for water rights and reduce the costs of application by small growers and community grower schemes, especially in relation to plantation forestry which experiences a more costly water licensing process.
- Resolve land claims and improve management of government-owned forests because many poorly managed government-owned forests in Eastern Cape have below average yields. Existing plantations can be rehabilitated to improve productivity. However, one of the major issues for state-owned plantations is that land claims have been lodged, making it difficult to proceed with improvements without resolution of the claims.
- Improve the viability of the sugar sector. Increased production costs since 2000 has rendered the industry less competitive. In addition, the world market price has been generally low due to over supply in the world market and world sugar trade liberalization. While depreciation of the rand could make sugar exports more viable, improved industry efficiency and risk management are also essential to maintain long-term industry resilience.

- Improve the efficiency/effectiveness of enterprise integration on mixed farms would be instrumental in increasing the performance of the subsystem, especially for smallholders.

Deciduous fruit and wine grape farming subsystem, South Africa

- Invest in quality training and education to improve the knowledge and skills of labourers (e.g. pruning) and commercial farmers (e.g. orchard management, irrigation management) and post-harvest operators. This will contribute to higher productivity, fruit quality and profitability, as well as competitiveness.
- Reduce production risks through using netting for shade and/or hail protection.
- Encourage orchard and vineyard replacement schedules to sustain long-term fruit and wine grape system productivity and quality.
- Improve clarity regarding land tenure, land reforms and implementation of the National Development Plan (NDP) for 2030, and smallholder development under the Agricultural Broadbased Black Economic Empowerment programme. These provide the context for orchards and vineyard replacement strategies, permanent and casual employment, food security and export potential of the subsystem.
- Improve strategic planning by fruit and wine grape farmers and the industry must adapt to a volatile and evolving climate, and market and policy contexts to build on technical efficiency (e.g. irrigation scheduling and cultivar selection).

Rainfed mixed subsystem, north Africa

- Improve domestic labour markets and inter-sector mobility to reduce rural poverty because exit from agriculture and increased off-farm income are important household strategies. While a substantial proportion of off-farm employment is located in the oil-rich states, continuation of domestic growth is important for farmer exit to other sectors.
- Increase the uptake of sustainable resource management and conservation agriculture to address the combined threats of degradation of grazing, and crop land and water resources (the latter largely in relation to depleting aquifers) and climate change limiting the opportunities for intensification. Therefore, sustainable resource management and conservation agriculture are strategic priorities.
- Broaden agricultural research to include a wider range of minor or novel products to support diversification and take advantage of new market opportunities. Agricultural research needs to look beyond the traditional major crops and livestock species, and anticipate the changes in consumer demand. Technology options need to be complemented by market and institutional measures to assure the availability of inputs and the possibility of competitive marketing – often requiring community cooperation.
- Develop policies to encourage private sector investment in input provision, processing and market development. Also, attention to product quality, food safety and often certification to ‘origin’ are important to meet demands of both domestic middle-class urban consumers and the European market.
- Facilitate increased operated farm size especially for smallholders. For young entrepreneurial households there are often prospects for growing herd size or, where land tenure permits, increasing operated crop area by leasing or sharecropping. In fact the relaxation of the State controls over the rental or sale of farmland is an important policy improvement to encourage rural adjustment.

African island farming system

Introduction

The main small island developing states (SIDS) surrounding the African continent are: Cabo Verde, the Comoros, Mauritius, Sao Tome and Principe, and the Seychelles Islands. (Guinea-Bissau and Madagascar have been considered in previous chapters on the major farming systems of continental Africa.) These islands share four key features which set them apart from mainland African farming systems: (1) small size restricts agricultural production, typically resulting in low diversity of crops and food products, and significantly increasing import dependence – but also creates opportunities for smallholder agriculture; (2) oceanic location gives the potential for fisheries and aquaculture (blue economy), but there are risks in shrinking agricultural land area and diminished availability of freshwater for agriculture; (3) remoteness means high transport costs to major import and export markets, often resulting in higher food prices; and (4) insularity creates small open economies, vulnerable to external shocks (IFAD 2014; UNECA n.d.).

Overview of the farming system

This section summarizes the farming system, identifies subsystems and the main drivers of change and considers system productivity. The island farming (and fishing) system has diverse populations, resources, climates and economies. Not surprisingly, the system has the smallest total and agricultural populations (respectively 3.8 and 1.5 million) of any of the farming systems analysed in this book. The system comprises only 280,000 farm households. However, as with many other African farming systems, extreme poverty levels are fairly high, averaging about 40 per cent.

Of the total area of just under 1 million ha, about 21,000 ha are devoted to agriculture, which is supplemented by some forestry and fisheries. The island agriculture commonly features mixed fisheries, tree crops, cereal and tuber crops, fruit, vegetables, spices and livestock, but the patterns vary widely across islands and depend on the availability of water. Typically, precipitation is higher closer to the coast, where more forest, tree crops and spices can be found. The main food crops tend to be grown in the hinterland. Farm

Table 15.3 Basic system data (2015): island farming system

<i>Item</i>	<i>Data estimates</i>
Total human population (million)	3.8
Agricultural population (million)	1.5
Total system area (million ha)	0.9
Cultivated area (million ha; % of total area)	0.2; 23%
Major agroecological zone	Subhumid-humid
Length of growing period (core range, days)	180–270
Access to services (low/medium/high)	low-medium
Agricultural population density (persons/total area; persons/cultivated area)	1.7; 7.3
Standard farm size (cultivated area/household)	0.8
Extreme poverty (% of rural population)	40

Source: Refer to Table 2.4.

sizes average less than 1 ha, or even less for smallholders managing land within estates, for example about one-fifth of the agricultural land in Comoros. The main exports are niche agricultural products, for example spices. A number of islands import more than half of their basic foodstuffs. On average, agriculture, forestry and fisheries contribute about 13 per cent to the national economies.

As mentioned earlier, different farming patterns arise due to the distance from the coast. This aside, from a food security and development perspective, the subsystems differentiate based on the strength of the island economy. Mauritius and Seychelles have a medium per capita income of approximately US\$10,000, whereas Cabo Verde, Comoros, and Sao Tome and Principe have per capita incomes in the range of US\$1,000 to US\$5,000.

Although half of the islands are quite urbanized (63 per cent in Cabo Verde), population growth is increasing the pressure on land. Productivity is low and agricultural development projects are working to reduce the yield gaps and poverty, for example the International Fund for Agricultural Development (IFAD) is introducing and testing technologies and strengthening social capital and financial systems. In the higher-income islands such as Mauritius and Seychelles, the domestic economy is a strong driver of farm intensification and diversification, including the provision of fresh, high-value produce to resorts and middle-income consumers in the modernizing cities. However, farming in the lower-income islands is vulnerable to imports of food and other necessities, and changes in international markets for specialized exports, for example *yang-yang* aromas from Comoros for the French perfume industry.

Household and national food security in the middle-income countries (Mauritius and Seychelles) is satisfactory, although nutritional status can be a concern. However, the lower-income island states are vulnerable due to their small size, isolation, narrow resource base, high population density and limited supplies of fresh water. They also exhibit substantial yield gaps in all forms of agriculture (including forestry and fisheries) but, in theory, good potential for increased productivity.

Strategic priorities

The farm households have a distinct set of strategies which shape their land management and market engagement choices. The extremely poor households focus on poverty escape through (in decreasing order of importance) non-farm employment, often in cities; diversification to higher value, more saleable products (e.g. new vegetables); intensification; off-farm income; and increased farm size or numbers of birds, livestock or boats (for fish-erfolk) to ensure household food security (Table 15.4). They have little capacity to invest

Table 15.4 Relative importance of household livelihood improvement strategies

<i>Poverty escape strategy</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>
Intensification	2.0	2.5
Diversification	2.5	3.5
Increased farm size	1.0	2.5
Off-farm income	1.5	1.0
Exit from agriculture	3.0	0.5

Sources: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

and limited ability to manage economic or climate risk. Strategies are different for better-off households, who focus on income growth through diversification, increased farm size and input-based intensification. These household strategies need to be understood and underpin broad-based national efforts to improve agriculture and fisheries.

Islands are niche production zones with two markets: feeding the island population, especially with perishable commodities and, potentially, exports to neighbouring islands or global (niche) markets. Island farming and fishing systems face high transportation costs (for exports and imports), little opportunity for economies of scale yet often ready, high-value markets from tourism and the middle classes in the cities. Not surprisingly, operational costs for development projects to reach beneficiaries in African island states (US\$172 per household) are about three times the average for mainland Africa (US\$65 per household) (IFAD 2014).

The development opportunities for the island farming system were identified by the Third International Conference on SIDS in 2014, namely, sustainable small-scale fisheries; smallholder agriculture, especially through market-oriented socially inclusive growth; and resilience to environmental and climate change. Strategic interventions in relation to population, food security and natural resources are often linked. Where resources permit, social protection programmes integrated with sustainable intensification activities hold good promise for the reduction of poverty and the improvement of household food security. An integrated approach to natural resource management is essential. For instance, Cabo Verde has successfully introduced drip irrigation technology, which has significantly increased productivity. IFAD has successfully strengthened farmer groups and increased productivity of food crops, horticulture and livestock by improved financial and other agricultural services, which contributes to substitution of food imports. Similarly, Mauritius is promoting the consumption of locally produced food and increasing domestic food production.

As noted earlier, fishing is important for livelihoods and for national economies in most SIDS. Mauritius has established six fishing reserves and two marine parks on the main island. Cabo Verde hopes that by mainstreaming climate change into development processes, the resilience of coastal and marine biodiversity will be enhanced, which will in turn reduce the vulnerability of coastal and fishing communities. Modernization of small-scale fisherfolk requires access to finance, insurance and market information – and better infrastructure.

The intensification efforts in all industries will require energy. Given their remoteness and small size, the island farming system would benefit from renewable energy resources such as hydropower, wind, solar, geothermal, biomass and wave power. Cabo Verde has developed a strategy to derive 50 per cent of its energy from renewable sources by 2050, while Mauritius aims to increase the share of renewable energy to 35 per cent by 2025. International financing and technological support will be crucial for the realization of such potential. For the private sector, there are significant opportunities for investment in renewable energy in the African SIDS.

Piloting new technologies is important, for example renewable energy production and decentralized use (mini-grids). Similarly, biological methods (e.g. rhizobia) might be more competitive than fertilizer imports in certain circumstances.

General economic growth will stimulate the farming system through the demand for food products. In this regard, boosting tourism is critically important for all SIDS, particularly where local employment can be created, local land and marine resources used, and demand for local food products stimulated (subject to sustainable limits).

The strengthening of local institutions, markets and policy frameworks is necessary to sustain individual and project initiatives. Genuine public-private producer partnerships will be important; small- and medium-sized enterprises have already contributed to the economic growth in Mauritius and Seychelles. Without doubt, additional investment and financing will be required. Several countries are establishing programmes to mitigate the impacts of climate change and comply with the UN Framework Convention on Climate Change; for example, Cabo Verde, Mauritius and Seychelles have already introduced national climate change strategies. Alongside this, the strengthening of adaptation capacity will improve the livelihoods of many of the extremely poor. Cross-cutting policy areas which require attention are: better collection and access to relevant climate change, biophysical and economic data and technologies; and mainstreaming sustainable development and climate change considerations into national planning, often in conjunction with partner countries on the mainland.

Conclusions for the perennial mixed and island farming systems

Although these two small and unusual farming systems are located on the periphery of the African continent, they have interesting lessons for the development trajectories of the larger mainstream farming systems analysed in the preceding chapters. The systems have subhumid to humid climates, with substantial climate variability. The nature and quality of soil and water resources is variable. The systems exhibit unusual institutions for collective action, market access and industry-policy linkages. There are strong drivers and trends which are shaping the evolution of both systems, noticeably demography, climate change and markets. Export markets are shaping the evolution of the perennial mixed farming system, whereas the island farming system suffers from isolation and, in general, challenges in sourcing affordable inputs and exporting produce. From a development perspective, poverty levels are low to moderate in both farming systems and are expected to decline. Household food security is, in general, adequate through home production or purchase from local markets, although malnutrition is an emerging concern. The farming system contributes significantly to employment, livelihoods and GDP.

To boost farm livelihoods and incomes and foster sustainable development, strategic interventions to strengthen market access and value chains would benefit all three sub-systems, as would greater attention to novel products and quality control. Two aspects of resource management will be important: land tenure and management; and water management and use efficiency. The maintenance of competitiveness will require increased investment in research on production and processing.

In contrast to the continental perennial mixed farming system, the island farming system has growing diversity with different development trajectories for each island. Therefore, solutions must be island and site specific, especially market-responsive diversification focused on urban and tourist sectors while maintaining natural resources. Although germ-plasm and expertise might be sourced from mainland Africa, provision of local farm inputs holds promise, especially the development of local renewable energy supplies from solar or wind. For those islands with speciality products or prospects of strong tourism growth, opportunities exist for sustainable development of the farming system.

In relation to lessons for other African farming systems, these two farming systems have had greater exposure to international markets, including European markets, for a long period, which has stimulated the development of formal and informal institutions for market intermediation. Both farming systems have also developed adaptive mechanisms

for dealing with climate variability over many decades, which could have applicability in other parts of Africa. There are also important institutional lessons. In the perennial mixed farming system, the sugarcane, forestry, fruit and grape subsystems have well organized and strong industry bodies which represent growers in policy debates and export negotiations. The arrangements under which smallholders supply forest, sugar or grape processing companies are relevant to the larger mainstream African farming systems.

Both these farming systems demonstrate the importance of ecological and economic niches in farming system development. Strong demand from nearby urban markets in southern Africa or tourist resorts in the islands has been exploited with moderate success in both farming systems. The market orientation, integration of diversified production and value chains and focus on quality and seasonality applies to the growing peri-urban farming system around major cities elsewhere in Africa, which currently lacks such effective institutions. Another lesson for the larger African farming systems is that the integration of production, processing and manufacturing in southern Africa also creates substantial employment in industries along the value chain.

Interestingly, a history of coping with shifting product and quality requirements in the market has led to balanced and flexible crop-tree-livestock systems. Whereas much agricultural intensification tends to lead to increasing specialization, these market-oriented farming systems have maintained substantial farm and landscape integration of annual crops, perennial crops and livestock.

Nevertheless, sustainable natural resource management is needed to enable continued adaptation to climate change and ensure the long-term viability of the system – this need is common to, and intensifying in, most of Africa because of increasing market and climate variability in many areas. Clearly, continued investment in national and regional research on production and processing, ideally coordinated between public and private sectors with emphasis on technology spill-ins, is important for competitiveness in local and international markets. Although often overlooked, functioning linkages between industry and policy makers are critical to enabling these farming systems to adapt and prosper in the context of changing climatic and market conditions.

References

- DAFF (2012) *Abstract of Agricultural Statistics*. Directorate of Statistics and Economic Analysis, Department of Agriculture, Forestry and Fisheries, Pretoria.
- FAOSTAT (undated) FAO database, FAO, Rome. www.fao.org/faostat/en/#data.
- Hortgro (2015) *Key Deciduous Fruit Statistics 2015*. Paarl, South Africa.
- IFAD (2014) *IFAD's Approach in Small Island Developing States: A Global Response to Island Voices for Food Security*. IFAD.
- Kotze, M. (2013) Economic position of deciduous fruit producers. Unpublished paper. Paarl, South Africa.
- SAWIS (2013) *South African Wine Industry Statistics no 37*. Paarl, South Africa.
- UNECA (n.d.) *Climate Change in the African Small Island Developing States: From Vulnerability to Resilience – The Paradox of the Small*, UNECA, Addis Ababa.
- van Wyk, G. and van Niekerk, P. (2013) The cost of wine grape cultivation and top achievers in difficult times. *WynBoer*, 284: 73–77.
- Warburton M. and Schulze R. (2006) *Climate Change and the South African Commercial Forestry Sector. An Initial Study*. ACRUcons Report 54, Forestry South Africa. www.forestry.co.za.

16 Urban and peri-urban farming systems

Feeding cities and enhancing resilience

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Key messages

- Urban and peri-urban farming systems (UPUFS) provide food and nutrition security for vulnerable urban populations and supply selected commodities across all regions of Africa, responding to urban unemployment and poverty as well as expanding domestic demand.
- UPUFS achieve higher yields with more limited space than rural agriculture due to availability of inputs including nutrients and labour; they recycle nutrients of which there is a surplus in urban areas.
- Productive urban household backyard and irrigated open space farms are commercializing, especially in perishables like dairy and small-scale horticulture, helping build resilient cities that can adapt to climate change.
- New policies and institutions must address food and nutrition insecurity due to lack of space in high-density urban slums as well as the opportunities UPUFS present for the intensification and modernization of the agriculture sector.

Summary

Urban and peri-urban farming systems (UPUFS) are significant in Africa because of the large numbers involved (40 per cent of urban households), the opportunities for intensification of urban smallholder agriculture and improving urban food security, and the potential flow-on effects for surrounding farming systems through rural-urban information and networking links.

The main driver of the farming system is rapid urban growth. Increasing demand for food motivates both subsistence production by food-insecure households and commercial production by small entrepreneurs. Two main subsystems have been identified: backyard and open space, with the open space subsystem further distinguished by irrigated and rainfed farming. The subsystems are found in both urban and peri-urban locations.

The main constraints are dwindling available space and non-agricultural development priorities. Lack of land tenure and the need to constantly shift locations makes the farming system insecure, particularly for the urban poor and open space subsystem. Specific policy initiatives are needed to ensure that the large numbers of food insecure urban households, mainly poor or headed by women, have access to land for farming. Around 77 per cent of urban poor households have been found to be food insecure in southern Africa. The poor

are also under-represented among UPUFS households. This is mainly because they live in dense slum settlements, which are hotspots of urban hunger and poverty.

UPUFS play an important role, however, not only for farm households but the city at large. They have a comparative advantage for intensification, if safely done, due to readily available wastewater and the nutrient surplus in urban wastes containing nitrogen, potassium and phosphorus (NPK). Peri-urban and urban farming systems have been shown to improve food security as well as incomes. The consumption of animal source foods, fruits and vegetables has beneficial effects on child health and nutrition security, suggesting urban livestock-keeping and backyard farming need to be supported. Corresponding food health and safety measures are needed to encourage health risk mitigation strategies based on current and continuing research.

With rapidly growing cities, low employment levels and weak infrastructure linking rural production to urban markets, UPUFS play a significant role. African cities, some of which are beginning to develop urban agriculture policies and institutions, can transition to being more sustainable and climate-change resilient through continued development of policies and institutions, especially by responding to urban farmers and their associations.

Introduction

Urban agriculture is as old as human civilization, with the history of cities intertwined with that of agriculture. Food production only separated from human habitation as agriculture industrialized. Before refrigeration, livestock came to town for slaughter, or were kept in urban fields and gardens from where livestock products were sourced. Such a situation is still found in many African towns and cities, and many of the urban parks in industrialized country cities were previously ‘commons’ where citizens grazed livestock. Farmers would come to urban markets; supermarkets and suburban food terminals appeared only in the 1960s.

Today, UPUFS proximity to the urban market facilitates horticulture, dairy and other food agribusinesses based on local urban demand as well as regional and international export trade. Increasingly people live in cities; while policy emphasis on food imports and export-oriented value chains has not provided sustainable food access and local economic development, the domestic markets are growing and providing UPUFS opportunities for short-cycle food chains.

Widespread availability of nutrients in the form of urban wastes enables intensification of UPUFS, but at the same time tenure insecurity prevents on-farm investment. Farmers suffer from the city’s economic pressure to convert to housing and other construction. While UPUFS are a low priority or illegal land use, they are vulnerable and have to constantly move.

Overview of the farming system and subsystems

UPUFS encompass not only the production of food from plants and animals but also the provision of agricultural inputs, processing, marketing and services to farming households and agroenterprises. The urban location makes several of these easier. UPUFS also serve non-agricultural functions, such as enhancing social inclusion, providing recreation, maintaining landscapes and biodiversity, and improving urban living conditions.

An estimated 40 per cent of urban households in sub-Saharan Africa, about 200 million persons, are expected to depend partly on urban and peri-urban agriculture (UPA)

Table 16.1 Proportion of households engaged in UPA in some African towns and cities

<i>City / town</i>	<i>Country</i>	<i>Survey date</i>	<i>Households engaged in specified UPA activity as % of total urban households</i>	<i>City population at survey date</i>
11 in southern Africa	9 SADC* members	2008 ^a	22% crops and livestock (only poor households measured)	varied
21 in west Africa		2006 ^b	20–50% crops and livestock	varied
Kampala	Uganda	2003 ^c	49% crops and livestock	1,200,000
Mbeya	Tanzania	2002 ^d	93% crops and livestock	266,000
Morogoro	Tanzania	2002 ^d	90% crops and livestock	228,000
Nakuru	Kenya	1998 ^e	35% crops and livestock	239,000
Dar-es-Salaam	Tanzania	1995 ^g	36% crops only	2,500,000
Kampala	Uganda	1991 ^f	30% crops and livestock	774,000
Nairobi	Kenya	1985 ^f	20% crops only	1,000,000
Addis Ababa	Ethiopia	1983 ^f	17% vegetables only	1,400,000

Source: Table adapted from Lee-Smith (2013).

Notes: ^a Frayne et al. 2010, ^b Drechsel et al. 2006, ^c David et al. 2010, ^d Foeken et al. 2004, ^e Foeken 2006, ^f Egziabher et al. 1994; ^g Mascarenhas 1999.

*Southern Africa Development Community.

by 2020 (Denninger et al. 1998; FAO 2012a). Its significance will increase as urbanization increases. Table 16.1 shows percentages of urban households engaged in UPA in various African cities based on different sources. Kampala, the only place for which data are available over time, shows an increase in the proportion of households farming. Estimates are not available for north Africa although many conditions are similar. Africa's urban population was estimated at 471.6 million in 2015, which would give an urban 'agricultural population' of 188 million in 2015 if the 40 per cent figure were correct.

A typical UPUFS household uses any available land to produce food for its own consumption using household labour, although it may dispose of part of its production, especially fresh vegetables and livestock products, through gift, barter or sale. UPUFS households are consistently larger than other urban households and farm more intensively on smaller plots than surrounding rural farms. UPUFS vary by location, with crop production predominating. Opportunities for intensification and commercialization are great due to demand for food.

While the poor predominate over middle- and high-income groups in urban Africa numerically, there is evidence that low-income groups are proportionally under-represented among urban farmers. This seems to be because the poor live mainly in dense urban slums without access to space. Higher-income groups are better able to farm, including the more profitable livestock keeping (Foeken 2006; Lee-Smith 2010, 2013).

The urban farmer

There is a wide variety of urban farmers. Many are poor, but lower and mid-level government officials and school teachers are also involved in agriculture, as well as richer people seeking investments. Some are recent immigrants, but many have lived long in the city, gaining access to urban land, water and other productive resources. Others are not from rural backgrounds but choose agriculture as one of their livelihood strategies.

Women constitute about two-thirds of African urban farmers, although their proportion varies between cities. Throughout the continent women are associated with subsistence food production and men with production for cash income. Thus women often form the bulk of labour on household farms but are less predominant in cash-crop production or as large livestock entrepreneurs (Hovorka and Lee-Smith 2006).

Types of UPUFS

Something that distinguishes urban from other farming systems is the fact that it is an integral part of the urban economic, social and ecological system. It has been defined as follows:

Urban agriculture is located within (intra-urban) or on the fringe (peri-urban) of a town, city or metropolis, and grows or raises, processes and distributes a diversity of food and non-food products, (re-)uses largely human and material resources, products and services found in and around that urban area, and in turn supplies human and material resources, products and services largely to that urban area.

(Mougeot 2000)

Peri-urban farms share characteristics with surrounding farming systems and merge into them along a rural to urban continuum. Peri-urban characteristics are understood to extend beyond urban boundaries for a distance of 15–40 km. Transect measurements from peri-urban to inner urban show the proportion of households farming and the area farmed decrease from peri-urban to urban (David et al. 2010; Dongmo et al. 2010; Drechsel and Dongus 2010), and these variables decrease with increasing size of the urban area (Lee-Smith and Memon 1994). Thus density and land availability are important drivers, in tension with demand.

UPA has been analysed according to many classifications, based on location, production scale and method, actors involved and degree of processing or marketing. There are backyard and rooftop gardens, community gardens, small-scale livestock, small-scale vegetable, institutional gardens and large commercial peri-urban gardens. Out of this variety, we identify two sub-types of UPUFS, both of which are found in urban and peri-urban locations: backyard subsystems and open space subsystems.

For both, issues of social equity arise in terms of land access, as well as questions of food and nutrition security and market access. We have developed this classification based on extensive consultation and review of the literature, including a recent analysis of African urban horticulture (FAO 2012a: 18). Within the open-space subsystem we have identified irrigated and rainfed types as a further categorization. As shown in Table 16.2, these differ from each other in terms of system structure and characteristics.

The urban backyard farm is the most common, constituting half to two-thirds of farming households (David et al. 2010; Foeken et al. 2004; Foeken 2006; Lee-Smith and Memon 1994). Probably the most significant in terms of household food security, it depends on space availability. Related to the home garden, it provides subsistence and the opportunity for urban enterprise. Further, it has demonstrated efficiencies in nutrient cycling through organic waste reuse and intensive space use, especially when both crops and livestock are involved. Besides home gardens, this category includes rooftops and institutional gardens and is more predominant in inner urban areas.

Table 16.2 Structure and characteristics of UPUFS subsystems

<i>System structure and characteristics</i>	<i>Backyard</i>	<i>Open space irrigated</i>	<i>Open space rainfed</i>
Main means of livelihood	Mixed, mostly non-farming	Mixed, mostly farming	Mixed, mostly non-farming
General size	2 m ² –0.2 ha	0.01–0.8 ha	2 m ² –0.8 ha
Crops/livestock	Mostly crop/livestock	Mostly crops only	Mostly crops
Location	Next to house	Along water courses	On public land
Tenure	Mostly secure	Mostly insecure	Insecure
Water source	Domestic water	Urban drainage	Mostly rainfed
Food vs income	Mostly for food	Mostly for income	Food and income

Figure 16.1 Open-space rainfed farming system in Kampala, Uganda.

Source: Gordon Prain.

The open space subsystem, more prevalent in peri-urban areas (Figure 16.1), includes not only small-scale operators producing vegetables but small-scale livestock systems and large-scale glasshouses producing fruit, flowers and vegetables. The extent of urban irrigated farming has been mapped at 24 million ha and urban open-space farming at 24 million ha globally, 11 per cent and 4.7 per cent of all irrigated and rainfed croplands respectively (Thebo et al. 2014).

The open space irrigated sub-subsystem (Figure 16.2), often using polluted water to grow crops, is the most productive and income-generating type of UPUFS, contributing up to 80 per cent of urban vegetable supply even when practised on marginal soils and with insecure land tenure (FAO 2012a). It is mostly managed by groups with a commercial orientation. The volume of water used varies with the season, type of crop and cultivation intensity. Watering is by bucket, watering can, or treadle and motor pump, and mostly involves overhead rather than furrow irrigation, which depends more on tenure security. Clean water is rarely used due to cost, unreliability or lack of access. In Lagos, peri-urban farming depends on the *Fadama* (wetland), which can be cultivated continuously using rivers, ponds, dug wells or wash-bores. Shallow hand-dug wells and streams are common in Niamey, Lome, Dakar, Kumasi and Cotonou. Deep wells were reported in Bamako, while Accra's urban farmers mostly use water from drains or polluted streams. Some farmers in Nairobi, Ouagadougou and Dakar use wastewater directly from city sewage.

The open space rainfed sub-subsystem is diverse, including small-scale opportunistic farming (on roadsides, under power lines, on empty lots, etc.), peri-urban horticultural plots and medium- to large-scale livestock grazing, including dairy. Less productive than the irrigated version, which also takes place frequently in public spaces, it is generally the last resort of the urban poor for food and income. Yet it also provides opportunities for urban entrepreneurs.

Figure 16.2 Open space irrigated crop production, Addis Ababa, Ethiopia.

Source: Diana Lee-Smith.

Variety and complexity in UPUFS

UPUFS systems interface with all other African farming systems. They vary across the continent, influenced by local topography, climate, food systems and preferences, usually similar to the surrounding agroecosystem, but all tending to intensify in response to the urban setting. Dairy and poultry mixed with maize or banana characterize farming in east African cities, while poultry and pigs mixed with fresh vegetables in the inland valleys, and cassava and numerous other crops in the upland systems, characterize the Cameroon capital, Yaoundé. UPUFS in towns and cities in arid and semi-arid lands cluster along watercourses and inland valleys, some taking advantage of water management systems developed over generations. For example, Bobo-Dioulasso, Burkina Faso's second-largest city, has vegetable production sites all along the Houet backwater, contributing to the city's annual production of about 50,000 tonnes of vegetables for its 0.5 million inhabitants.

Agroforestry systems are important components of UPUFS. Maintaining a few fruit trees within a home garden is an age-old practice, but expanding urban populations now provide a growing demand for both fruit and ornamental tree species. This has given rise to flourishing tree nursery enterprises in most African cities. Agroforestry systems in urban and peri-urban gardens in Niamey, Niger, have a richness and diversity of species that suggest these household enterprises contribute to conservation of genetic resources.

Small- and medium-scale aquaculture around African cities takes advantage of the market and the availability of (waste)water. Urban demand for fish drives growth of peri-urban aquaculture in Nigeria, developed through medium-scale enterprises and cooperatives that support input industries such as specialized feed producers. Poultry manure is widely used to fertilize ponds and experiments are ongoing with waste water ponds.

The hot-spots of poverty and hunger in UPUFS are high density slums. In some cities slum households may have access to nearby open spaces where they produce food, but generally they have less access to space than other urban residents, e.g. only 5 per cent in Nairobi compared to 20 per cent for the city as a whole. UPUFS bright spots of success are the intensive micro-gardens in some dense settlements where the local authorities and other institutions support communities in producing healthy food.

Trends and drivers of change across the system

The main driver of UPUFS is urban expansion and the demand for food, motivating both subsistence and commercial production. Intensification of UPUFS is driven by water and nutrient availability, with greater availability a major difference between rural and urban farming locations (Figure 16.3). Land tenure is a major constraint to food security for the urban poor. Middle- and higher-income urban households generally have access to backyard space with formal tenure whereas low-income urban households mostly live in slums where tenure is unrecognized (Boxes 16.1 and 16.2). Lack of space in dense settlements is a driver of the open space urban farming subsystem, whether found in urban or peri-urban open spaces, but tenure insecurity of those open spaces underpins increasing food insecurity for the urban poor (Box 16.3). Restrictive policies and regulation have affected UPUFS negatively, as have many market conditions, including for example frozen imported chicken competing with local farms. These have driven some peri-urban poultry farms into bankruptcy in west Africa. The main UPUFS drivers are summarized in Table 16.3 and discussed below.

Figure 16.3 Sylvia Oluoch's backyard crop-livestock farm: Nutrient-rich livestock waste discharge fertilizes crops.

Source: Diana Lee-Smith.

Box 16.1 A household typical of the UPUFS backyard subsystem

The household comprises a nuclear family, the husband working as a teacher while the wife manages the farm, located off a main arterial road leading out of Yaoundé. They keep pigs and poultry as well as growing a variety of crops including banana, cassava and different green leafy vegetables. Of their four children, two are in primary school, one in secondary and one, a high school dropout, helps on the farm. All the children and the husband work on the farm when they are available, such as during school holidays. The husband makes decisions on farm management, especially on purchases and sales of livestock and inputs, although he consults with his wife. Farm income and teacher's salary combine to give a household income more than twice as high as the national average. The husband inherited the 0.4 ha from his father who bought it when he migrated in the 1970s, giving them secure tenure.

They recycle all domestic organic waste on the farm. Food waste is used for the pigs in addition to purchased feed supplements. They have two types of poultry: free-range and broilers. They consume the free-range poultry and sell broilers to local kiosks. Piglets are sold to traders. They use pig and poultry manure to fertilize their crops and sell surplus manure to neighbours. Water collected from the house roof is stored in a large plastic drum and used to water crops during the dry season.

Crops grown are for home consumption with the surplus being given away as gifts or sold, especially in the dry season when prices are higher. They come from a village in southeast Cameroon where they support extended family members.

Box 16.2 A household typical of the UPUFS open space subsystem (high density slum)

The household consists of a young man, his wife and baby, living in one room in a Nairobi slum. He is formally unemployed, but collects waste from other slum dwellers and surrounding high-rise buildings and sells recycled items to traders in the slums. He has also started a waste recycling business with a four-member youth group. They make charcoal briquettes for sale as cooking fuel to other slum dwellers. His daily single meal of maize and beans is purchased from a street vendor, using the income he gets from this business. He started farming with his youth group during the post-election violence in 2008. From that he is sometimes able to feed his family with fresh vegetables. They are not well-nourished, however, and the baby gets sick when the mother does not have enough milk.

The farming group was given the piece of land on the railway reserve through the intervention of a community leader when they were starving. It used to be a waste dump. It is rich in nutrients because of the organic waste fraction (including human waste), but also has high heavy metal contamination. They grow mostly kale, cabbage, pumpkins, some sweet potato and indigenous green vegetables, which they have been told take up less heavy metal than kale and cabbage. These crops are also sold to neighbours for group income. They have a water tank, also provided through community interventions, and have drip-feed water pipes along the rows of vegetables. The slum community is currently threatened by railway and road development, even though this tenure is relatively secure having been granted by the colonial government in the early twentieth century.

Box 16.3 Key challenge

Increasing the food security of the urban poor represents the main challenge for UPUFS. This challenge needs to be linked to the potential for intensification, which, if realized, may not only increase urban food supply, but have flow-on effects for surrounding rural farming systems through feedback of information via rural-urban household links and institutional networks.

Key participants in addressing this challenge are urban local governments and farmers' organizations.

Options for change include increased use of: micro-spaces in densely populated areas; available recyclable nutrients from organic wastes for soils and animals; available water (especially wastewater); and un- or underemployed household labour. Policies are needed that will address the food security needs of the urban poor, especially women-headed households. Allocation of public lands for this purpose is appropriate, as was the case with Maputo's *zonas verdes* (green zones) from the 1980s.

Population, hunger and poverty

Africa's urban population 2000–2030 is projected to increase by an additional 367 million, over twice rural growth, with urban poverty increasing in parallel. Natural increase contributes a high proportion of urban growth, while rural-to-urban migration in Africa is more commonly seasonal and cyclical than one-way. Members of multi-locational households move between city, peri-urban and rural areas. They use both urban and rural resources for agricultural and non-agricultural livelihood strategies that respond to poverty but also have potential for economic growth. Multiple rural-urban linkages comprise labour, agricultural inputs, marketing chains, micronutrient flows, and social and political ties and obligations including remittances. These stimulate and intensify both urban and rural agriculture (Prain et al. 2010).

Urban poverty can be underestimated if poverty lines ignore the higher cost of living in cities. With a poverty line of US\$2 a day, the poverty level is close to 70 per cent, or more than 200 million people, while the number of people living in slums in sub-Saharan Africa almost doubled between 1990 and 2010, from 102 million to 200 million (FAO 2012a). Some 77 per cent of low-income urban households in selected southern African cities were food insecure and 92 per cent had gone without food due to price increases in 2008 (Frayne et al. 2010). Some food insecurity was seasonal, as in rural areas, possibly because of rural food transfers but also seasonality of employment such as construction (Battersby 2011).

Natural resources and climate

Land and water availability are key drivers of UPUFS. Irrespective of soil quality, an urban backyard space will turn available land into a productive farm through the combination of livestock manure and garden crops. Roof and other water run-off complement this.

The open space irrigated sub-subsystem is dependent on the availability of (usually public) land adjoining a watercourse. Increasing urban water demand generating a return flow of wastewater and a lack of alternative sources are driving the sub-subsystem. Cultural constraints and risk awareness do not prevent use of such nutrient-rich water for agriculture. The extent of irrigation with partially or untreated wastewater is usually underestimated, as are the numbers of beneficiaries including farmers, traders and consumers (Raschid-Sally and Jayakody 2008).

The open space rainfed sub-subsystem operates in much the same way as surrounding farming systems. Where urban livestock are allowed to become part of these subsystems, similar patterns of natural resource use may be found as in the backyard subsystem.

Climate change is a challenge for cities, disproportionately affecting people who live in slums on hillsides, in poorly drained areas or in low-lying coastal zones. In parts of Africa climate change is also predicted to cause long-term displacement of people affected by drought or flooding from rural to urban areas (UN-IASC 2010). The World Meteorological Organization (WMO 2007) suggests that urban farming can play a role in adaptation to climate change and to some extent in mitigation, and should be encouraged. The Food and Agriculture Organization (FAO 2008) also concluded that it builds city resilience in various ways including through diminished dependency on imports.

Energy

Inherently, UPUFS are energy-conserving because of their proximity to markets, capacity to absorb and recycle wastes as nutrients, and lower transport energy costs, both in terms of transporting food to urban consumers and transporting readily available soil nutrients (urban wastes) to farmers. This is not yet part of energy equations or planning for either sustainable agriculture or sustainable cities. UPUFS assist the absorption of excess urban nutrients which are otherwise dealt with as wastes, with energy needed for their disposal.

Higher availability of electricity in urban areas may drive UPUFS, but this has not been measured.

Human and social capital

Research-to-policy platforms have helped create new institutions on UPUFS, build human capital and facilitate knowledge-sharing. Urban Harvest (of the Consultative Group on International Agricultural Research) and the international network of Resource Centres on Urban Agriculture and Food Security (RUAF) have contributed to this, while regional training courses in Francophone Africa (1999), Anglophone Africa (2004) and Middle East and North Africa (2005) have also helped. Recently, the UN's Food and Agriculture Organization (FAO)'s 'Food for Cities' initiative achieved world-wide impact through its electronic discussion blog, which followed older global civil society platforms such as 'City Farmer'.

RUAF's 'From Seed to Table' programme has been strengthening urban farmer organizations since 2009, by supporting capacity for farming innovations, micro-enterprise development (in production and processing) and marketing (value chain development) in 17 African cities. Value chain projects (farmer-led enterprises) have been set up for production and processing of vegetables or livestock products and their direct marketing to consumers, schools, supermarkets and restaurants.

Gender roles vary across Africa and to some extent determine UPUFS function. Where men dominate urban irrigated vegetable production, it tends to be an individual business activity. Yet such farming is dominated by community groups of women in Banjul and individual women in Freetown. In Yaoundé, 87 per cent of crop cultivators are women, even the commercial ones (79 per cent). This is not the norm in west Africa, however, where a gender study of 20 cities found men dominated urban irrigated vegetable farming and women the vegetable retail sector. Certain crops are associated with one or other gender while women have limited access to land or starting capital and engage less with irrigation.

In east Africa, women farmers dominate urban irrigated cropping as well as the overall numbers of farmers. Men dominate livestock production, especially large livestock, although women often do livestock-keeping tasks. It is suggested that women's roles may be changing as a result of urbanization itself, although women-headed households have also been identified as an urban poor group vulnerable to food insecurity. The limited access to land for food production by poor households is exacerbated for women due to their traditional lack of land rights.

Science and technology

Technology development for low-income UPUFS has been documented since the late 1990s by RUAF. International partners including Urban Harvest, the International Water

Management Institute (IWMI), UN-Habitat and FAO have assisted with innovations, especially on solid waste and wastewater reuse, as well as space-intensive urban gardening, a major driver of UPUFS intensification.

However, more attention is needed on these new ways of urban food production. Intensification through technologies such as vertical farming in slums (using containers or built surfaces) can drive improvements in household food security. For example, 11,000 households in Nairobi's Kibera slum have 'sack gardens' providing fresh produce and enough money from sales to cover their rent. Conditions with limited rural significance affect UPUFS. Apart from the use of micro-spaces and recyclable nutrients, research is needed on poor or insufficient soil, affordable biomanagement of insect and disease pests at high human population densities, and managing high-risk contaminants. Pioneer research on these issues in Cuba has yet to be mainstreamed in Africa. However, research demonstrating the primacy of UPUFS in the east African dairy sector and in vegetable production, including indigenous species for local markets and exotics for export, has been done in national agriculture research institutions (NARIs) supported by international institutions.

Concerns about food safety have led to studies on biological (pathogenic) and chemical (toxic) contamination through the air, water and soil pathways that can affect urban-produced food, but more work is needed. A comprehensive study of the health risks and benefits in Kampala established a statistical relationship between consuming animal source foods and child health and nutrition security, and between urban food security and livestock rearing. This suggests the benefits of urban livestock keeping balance the health risks. Urban farmers use many health risk mitigation strategies, with over 90 per cent avoiding biological contaminants in milk by consuming it as tea, boiled with water and tea leaves. When farmers have access to services such as water and believe that UPUFS are legal, they use more and better risk mitigation strategies (Cole et al. 2008; Prain et al. 2010).

Low-cost options are available for mitigating the health risk of using wastewater while maximizing its benefits (Keraita et al. 2008). Partial and non-treatment options are permissible in the revised World Health Organization (WHO 2006) guidelines for wastewater use in irrigation. In Africa these are being locally adapted at different entry points (e.g. drip kits, on-farm treatment, crop restrictions, good vegetable washing) as pathogen barriers (Amoah et al. 2011).

Trade and markets

Urban demand for food and non-food agricultural products influences trade and markets. Proximity to urban demand and international market connections spur commercial horticulture in a number of African countries. There are also small-scale sales to local markets by UPUFS households, especially within the open space irrigated sub-subsystem. Urban Harvest research shows the backyard farming subsystem commercializes more where livestock production is included (Prain et al. 2010). Livestock as a part of backyard mixed crop-livestock systems range from chickens, rabbits and grass-cutters, to sheep, goats, pigs, cattle or camels. Livestock are a repository of exchangeable wealth throughout Africa, and the urban system is no different.

Urban livestock have generally been neglected as an aspect of trade and market data. Data on urban livestock numbers in relation to human population are not widely kept, but the Kenyan census now complements research. In 2009, Nairobi had 3.9 million

people and 55,000 head of cattle, compared with 1 million people and 23,000 cattle in 1985. Nakuru in Kenya had 239,000 people and a cattle population of 25,000 in 1999 (Foeken 2006; Lee-Smith 2013). Crops produced in the open space subsystem are sometimes supplemented by livestock. Despite an unfavourable policy environment, livestock are grazed on roadsides or other vacant land, or kept in zero-grazing stalls in dense slum settlements.

While most UPUFS produce for household use and even commercial producers consume part of their production, such households also make a significant income from sale. Irrigated vegetable producers exceed official minimum salaries by a factor of 1.6 up to 10. Farmers in Kampala, Dar-es-Salaam, Yaoundé and Addis Ababa all had higher than average incomes. Factors influencing net UPUFS income are: degree of market orientation, farm size, household labour availability, choice of crops and animals, availability and cost of inputs (especially cost-saving items like organic wastes and wastewater), dry-season irrigation, technology and capital availability, access to markets, prices obtained and the ability to store, process and preserve products. Households also benefit from processing and marketing (e.g. ghee making, preparation of street foods, street carts or small local shops, and cleaning and packaging food for sales to supermarkets) and from farmer organizations. Market research in Kampala showed that demand for UPUFS products is high and exceeds supply in outlets ranging from corner kiosks to supermarkets.

Nutrients that are both produced and used by UPUFS are also traded locally, in the form of feed, manure and compost. Trading the nutrient surplus from urban to rural areas is uneconomic although some rural-urban recycling of crop residues and food wastes has been documented (Karanja et al. 2010). Most food wastes, crop residues and manure are recycled within urban backyards or exchanged informally through gift or barter. Trading in compost has been documented in Nairobi, with supply far below demand.

African trade and markets are rapidly moving towards the industrial model of food production and consumption in the twenty-first century, the trend being most advanced in South Africa, where supermarkets are the norm. While such food purchases are often unaffordable to the urban poor majority, they represent a relatively untapped opportunity for UPUFS to sell produce.

Policies and institutions

UPUFS have been routinely excluded from urban policies and institutions even though the 'garden city' concept is at the root of modern urban planning. They only reached policy attention in the 1990s due to their visibility, the effects of Structural Adjustment Policies (SAPs) and research publications. The International Development Research Centre (IDRC) book *Cities Feeding People* revealed that one-third or more of east African urbanites were feeding themselves partly through their own urban production (Egziabher et al. 1994).

Except for the Tanzanian self-sufficiency movement, which supported urban gardens in the 1960s, official attitudes to UPUFS in Africa only became positive in the economic crisis of the 1980s to 1990s. SAPs led to reduced subsidies, decreased infrastructure investments, lower farm incomes and increased urban unemployment especially among public sector workers. UPUFS provided a survival strategy. However, at first the policy response consisted of 'turning a blind eye' rather than institutional support.

Some African governments have instituted measures supporting UPUFS, such as Tanzania from the 1980s to the present, and Zimbabwe recently. Other examples are

Table 16.3 Drivers of farming system evolution

<i>Drivers of farming system evolution</i>	<i>Trends and drivers</i>	<i>Implications for farming system structure and function</i>
Population, hunger and poverty	Urbanization and unemployment	Space availability becomes critical
Natural resources and climate	Reuse of wastes as inputs	Intensification, food safety issues
Energy	Green economy and resilience agenda	Farmer-government coordination
Human and social capital	Stakeholder platforms, gender roles	Official recognition, women's empowerment
Science and technology	Health impacts, space saving systems	Regulation, intensification
Trade and markets	Demand for perishables	Increased value-addition
Policies and institutions	Creation of urban food institutions	Better urban food governance

Mozambique's 'Green Zones' during its civil war, and post-civil war production in Sierra Leone. There is increasing attention to the roles of UPUFS in rehabilitation (as in Sierra Leone and Liberia), small business and value chain development linking urban and rural agriculture, and climate change adaptation.

Formal policy and institutional development followed benchmarks such as the 2002 Declaration on Feeding Cities in the Horn of Africa and the 2003 Harare Declaration on UPA Policy. The City of Kampala, for example, which had an Agriculture Department following decentralization in the 1990s, passed urban agriculture and livestock ordinances in 2006. Nairobi has had a Department of Agriculture since 2013 and passed legislation in 2015. Institutions incorporating farmers and their associations in active debate with local government, such as those in Accra, Ghana and Nairobi, have greater impact in institution building than those which do not.

System and subsystem performance

The standard data used throughout this book on intensification, diversification, change in farm size or increases in off-farm income, are not available for UPUFS. Therefore the available empirical findings, though not usually disaggregated by subsystem, are summarized based on expert judgement in Table 16.4. This takes sustainability to mean non-depletion of soil resources over the longer term.

Table 16.4 Overall performance of UPUFS system and subsystems

<i>Performance</i>	<i>Backyard</i>	<i>Open space irrigated</i>	<i>Open space rainfed</i>
Productivity	Medium	High	Low-medium
Sustainability	High	Medium	Low-medium
Human development	High	High	High

Productivity

There are hardly any data available on UPUFS productivity, although there is much anecdotal evidence that the open space irrigated sub-subsystem in particular is extremely productive. Policy support has been suggested as a driver of high UPUFS productivity. For example, Malawi's fertilizer subsidy enhanced UPUFS productivity, especially the open space subsystem, during economic downturns. Water and nutrients enable intensification of UPUFS because of their high availability in urban areas (Figure 16.4). Productivity increasing with proximity to (and size of) the urban area was associated with higher use of inputs (especially water and organic waste materials) on small plots in one national survey.

Resilient sustainable development

While UPUFS impact the urban environment in a number of ways (greening, landscape development, climate change impact mitigation and so on), here we focus on performance in nutrient cycling, which has implications for sustainability through soil amendment. Urban areas are immense producers of nutrient surpluses, which are diluted in the

Figure 16.4 Ruth Wanyoike weeding vegetables irrigated using wastewater in Kahawa Soweto, Nairobi, Kenya.

Source: Mary Njenga.

Table 16.5 Area of irrigated open space in selected cities of west Africa

City	Population (000) in 2005	% growth*	Irrigated area (ha)	Annual rainfall (mm)	Irrigated ha/1,000 population
Nouakchott	700	8.6	150	130	5
Dakar	2,500	3.9	150	450	16
Niamey	900	5.6	400–600	545	1.5–2.3
Lome	900	4.8	60	688	15
Cotonou	1,100	4.6	36	795	31
Accra (mega)	2,700	4.6	47–162	810	17–57
Bamako	1,400	4.3	300–650	856	2–5
Ouagadougou	1,200	6.1	25–43	880	28–48
Tamale	200	2.5	33	1,033	6
Banjul	40	4.3	45	1,096	0.8
Kumasi	1,100	5.9	41	1,432	27
Yaounde	1,800	4.6	90	1,600	90
Lagos	13,000	4.9	130–325	1,740	130–325
Freetown	1,100	5.7	45	3,590	24

Source: Drechsel et al. (2006).

*based on urban boundaries, although in some cities, like Accra, these boundaries are outdated and growth in peri-urban districts (6–9 per cent) better reflects urbanization.

wastewater stream. Table 16.5 shows that in various cities, 20–650 ha are under UPUFS open space irrigation, consistent with global figures (Thebo et al. 2014). These areas may produce three to ten crops per year.

However, the open space irrigated sub-subsystem does not maintain soil quality as well as it should. Large quantities of pesticides are often used to sustain output to maximize incomes. The open space rainfed sub-subsystem generally has lower output and less nutrient input. In cases where there are chemical fertilizer subsidies, as in Malawi, soil quality maintenance can also be problematic.

Apart from waste water, millions of tonnes of solid waste are produced annually in sub-Saharan Africa's urban areas, suggesting high nutrient-cycling potential. Although an estimated 2,223 tonnes of nitrogen (N), 2,223 tonnes of phosphorus (P) and 3,700 tonnes of potassium (K), worth about US\$2 million, are generated annually in Nairobi, for example (Njenga et al. 2010), exporting this to rural farming systems is not easy due to marketing constraints: without an organized market, value addition or subsidies, it is not as feasible to transport waste as it is to transport the food it comes from.

Nevertheless, at the small scale within UPUFS, and especially in the backyard subsystem, the situation is different. Quantitative evidence from east and central Africa suggests as much as 90 per cent of food wastes are recycled as livestock feed within the backyard UPUFS, and the other 10 per cent as compost. Crop residues are also mostly recycled as feed, about a quarter going to composting, while 48 per cent of livestock farmers use manure from their animals for crop cultivation on their own backyard farms. Figures on livestock manure reuse within UPUFS are given in Box 16.4.

While small-scale backyard crop-livestock farmers make use of cities' solid wastes, this is outside the framework of policy or planning either by the urban or agriculture sectors (Karanja et al. 2010). Likewise, open space subsystems, irrigated or rainfed, could achieve higher performance and sustainability through planned management.

A contentious area is the reuse of human waste in UPUFS. Human and animal excreta have been applied to fields in China for thousands of years, and large cities in Europe grew much of their food in swamps where human wastes were dumped until awareness of the link to the spread of disease limited its application in the nineteenth century (Cole et al. 2008). In 2006, the WHO, in collaboration with FAO and UNEP, published guidelines for the safe use of waste in agriculture, including human waste (WHO 2006). One person produces the equivalent of 7.5 kg/yr of straight NPK, enough to produce 250 kg of cereals. Recent research has investigated ‘closing the loop’ through safe recycling (Cofie et al. 2010) including the ‘Peepoo Project’ where biodegradable bags are used for excreta disposal. Evaluation of these bags in sack gardens in Kibera slum in Nairobi found that the addition of 50 bags increased soil macronutrients ($P < 0.001$) with increases in total N of 625 per cent, organic carbon 710 per cent and P 3,000 per cent respectively above the control. Soil moisture content was also significantly higher than the controls.

Box 16.4 Potential for improved performance through managing municipal nutrient flows

Studies in Nakuru, Kenya, show nearly all domestic waste generated by urban farm households was used as livestock fodder. Almost half the manure generated was reused productively, although while middle-income backyard farms achieved a very high reuse rate of 88 per cent, those in low-income high density areas who use open spaces only achieved 17 per cent reuse. Some 61 per cent of the recycled manure was used directly on the same urban farms, 6 per cent went to rural farms and the rest was sold or used elsewhere in town. But 54.5 per cent (154,000 tonnes fresh weight) of the total manure production mostly from high density areas, was dumped alongside other solid waste (Karanja et al. 2010).

In Yaounde, Cameroon, 69 per cent of poultry and pig manure generated in the city and its environs (20,600 tonnes annual dry weight) was utilized in farming, mostly within the same mixed crop-livestock backyard farms, but 10 per cent was sold outside the city, notably in a provincial urban capital, Bamenda, where it fetched a higher price (Dongmo et al. 2010).

Organized collection and reuse of livestock wastes from low-income farms in high-density areas (as is being initiated in Nakuru) would greatly increase the economic efficiency of food production as well as waste management. Likewise, planned reuse of urban organic solid waste in urban farming would improve food production, waste management and ecological cycles for sustainability. Policy opposition to urban livestock must be rethought in light of livestock’s role in incomes, nutrition and nutrient reuse.

Human development outcomes

FAO and the World Bank found that engagement in urban farming corresponded with greater dietary diversity in 10 out of 15 countries (Prain and Dubbeling 2011; Zezza and Tasciotti 2008). The comprehensive health study in Kampala (mentioned under science and technology as a trend or driver) found that wealth was the main factor affecting

household food security, but that UPA mediated this. Nutrition security (for which food security is a necessary but not sufficient condition) was linked to the same factors (Cole et al. 2008).

In Kampala, children and adults get much of their protein and micronutrients from milk, usually taken for breakfast in the form of tea, whereas in Yaoundé there is virtually no dairy (only poultry and pigs) and the city's poor meet their calcium needs by eating groundnuts with fresh leafy vegetables, which also supply protein and micronutrients. A variety of traditional leafy vegetables is grown in both backyards and open spaces, providing 8 per cent of the protein and 40 per cent of the calcium consumed in the city (Bopda et al. 2010). By comparison, Nakuru, Kenya, UPUFS supplied 22 per cent of the food intake of farm households and 8 per cent of the town's overall food and nutritional needs. UPUFS in Dar-es-Salaam provided 90 per cent of the city's leafy vegetables and over 60 per cent of its milk (Foeken 2006; Karanja et al. 2010). But the contribution of UPUFS to household food security is more important in terms of fresh produce than calories, as most staples which support the daily calorie intake derive from rural cereal or tuber production. Backyard systems analysed in Accra and Kumasi only contribute 10 per cent or less of household food demand.

UPUFS complement rural systems and increase efficiency in national food supply (Figure 16.5) by providing perishables, especially where roads are poor and cold

Figure 16.5 Open space irrigated farming in downtown Kampala, Uganda.

Source: René van Veenhuizen.

storage scarce. They complement rural production in the dry season and when rural areas are poorly accessible during rains they also stabilize the market. Finally, by substituting food imports intended for urban consumption, they save foreign exchange. These factors could be enhanced by policies supportive of UPUFS households (van Veenhuizen 2006).

The Overseas Development Institute (ODI) examined the role of UPUFS in poverty reduction in developing countries through expenditure substitution (savings), income from marketing and labour, and access to cheap food (price impact). Savings and price impacts represent coping strategies, while income from marketing and labour have more potential to affect poverty. FAO contrasted shares of income from (urban) agricultural activities in Africa and other regions. Over 50 per cent of the income of the urban poorest in Nigeria originates in agriculture and 20 per cent or more in other African countries, while non-African numbers are much lower.

The relationship between UPUFS and poverty alleviation must be carefully examined, however. Is promotion of UPA a worthwhile strategy to ensure urban dwellers are food secure through their own production, or would a more effective strategy be intensification to provide business opportunities and enhance local availability of food? Studies in southern Africa (Crush et al. 2010) found such high levels of food insecurity in low-income areas, even in places like Cape Town and Johannesburg, that the former strategy looks essential to address urban food insecurity in the short term. This is in fact the default strategy employed in many African towns and cities in economic crises, where UPUFS are either encouraged or simply tolerated.

A World Bank-commissioned study in Nairobi and Accra as well as cities outside Africa found that savings from producing food were substituted for expenditure on staples and higher value dietary items such as animal source foods and other vegetables. With over 30 per cent of producers considering UPUFS an important source of income, and a conservative estimate of 20 per cent of the urban population involved in agriculture, it is estimated that over 420,000 households in Accra and Nairobi generate an important share of their income from UPUFS. Agriculture was said to be more compatible than petty trading or casual labour with other kinds of urban work, facilitating multiple income sources. Income generation was sometimes considered more important than access to additional food as a reason for production (Prain and Dubbeling 2011).

UPUFS households are better off than the norm. In Kampala 70 per cent and in Dar-es-Salaam 67 per cent of farming household heads earned above average incomes. In Yaoundé wastewater irrigation farmers had incomes 50 per cent above the minimum wage, and all Addis Ababa crop farmers had incomes well above the median. In east Africa both commercialization and higher incomes have been associated with livestock production, with its opportunities for the sale of products such as milk and eggs in addition to meat. These are mostly backyard farmers. It is claimed that anyone in Dar with a vegetable garden and one or two cows can earn more than the basic government salary. Danso et al. (2002) showed that irrigated open space urban vegetable farming can achieve an annual income two to three times that earned in rural farming, and urban intensive, small-scale farmers earn at least twice as much as rural farmers on only about 20 per cent of the area. A farmer producing throughout the year will jump over the poverty line of US\$1 per day, although without water access other income sources are required in the dry season. UPUFS can be profitable for households producing products that are in high demand and have a comparative advantage over rural production. These are perishables such as green leafy vegetables and milk, as well as mushrooms, flowers and ornamental plants.

A causal link between urban farming and poverty alleviation has, however, yet to be established. Longitudinal urban cohort studies, controlling for land area and other variables, are needed to sort out the direction of the relationship: do UPUFS alleviate poverty or does being better off help a household engage in UPUFS? While it is clear that UPUFS, particularly backyard and irrigated subsystems, present opportunities for increased agricultural productivity and higher incomes, these opportunities are less available to the urban poor living in dense slums.

Strategic priorities for UPUFS

UPUFS can contribute to the development of a sustainable city that is inclusive, food-secure, productive and environmentally healthy, including adaptation to climate change. The urban nutrient surplus, high demand, availability of underemployed labour, and shortage of land all drive intensification and indicate directions for sustainable cities. UPUFS have the potential to contribute to these goals if understood, recognized and supported by policy.

As Tables 16.6 and 16.7 show, the five poverty escape pathways for UPUFS are configured differently from rural farming systems. In particular, urban farming generally lacks policy and programme support to allocate land, add value and recycle nutrients. Changing this is a strategic priority. The fifth pathway out of rural poverty, exit from agriculture, is rather the reverse for the urban poor, especially women-headed households who need to farm but cannot get access to land. While low-income groups are underrepresented among urban farmers in proportion to their overall numbers, urban farmers in fact earn higher than average incomes. On the other hand, we may speculate that some may indeed do so well that they choose to exit from agriculture.

Table 16.6 Potential and relative importance of UPUFS for poverty reduction

<i>Strategies for poverty reduction</i>	<i>UPUFS</i>	<i>Backyard</i>	<i>Urban irrigated</i>	<i>Open space</i>
Intensification	3	3	2	2
Diversification	2	3	2	2
Increased farm size / land area	2	0	3	4
Increased off-farm income	2	3	2	1
Exit from agriculture	1	1	1	1

Source: Authors' judgement.

Note: Total score for each farming system equals 10.

Table 16.7 Relative importance of household livelihood improvement strategies

<i>Livelihood improvement strategy</i>	<i>Extremely poor (2000)</i>	<i>Extremely poor (2015)</i>	<i>Less poor (2015)</i>	<i>Total population (2015)</i>
% of total urban ag pop	—	50	50	100
Intensification	1	2	3	2.5
Diversification	3	2	3	2.5
Increased farm size	3	4	0	2
Off-farm income	3	1	3	2
Exit from agriculture	0	1	1	1

Source: See Chapter 1, 'Farm household decisions and strategies' and Chapter 2, 'Household strategies'.

Current estimates of the scale and numbers of urban households farming (Denninger et al 1998; Thebo et al. 2014) need to be verified. Estimates of the proportion of poor and very poor in Table 16.7 are based on the principles set out earlier.

Population, hunger and poverty

As a result of urban population growth, African UPUFS represent a large and growing phenomenon directly linked to food security and also to income. They improve food and nutrition security, including through fresh vegetables, livestock-keeping and consumption of animal-source foods. The key intervention for this farming system is policy recognition and access to land for food production by those who are food insecure (Table 16.8), in particular poor households headed by women.

Natural resources and climate

Food production needs to be recognized as an urban land use (Figure 16.6). By diversifying food and income sources, UPUFS reduce vulnerability and strengthen community-based adaptive management. Africa can take advantage of improved understanding of food systems to create more sustainable and resilient cities. UPUFS

Figure 16.6 Open space irrigated crop production in Cape Town, South Africa. Drip feed irrigation was provided by the City Council.

Source: Diana Lee-Smith.

build social inclusion, a safety net for poor households and enable some households to develop businesses along short food chains. Metropolitan or city region planning helps stimulate enhanced food security and economic growth and works with rural-urban linkages, although African cities still face the challenges of poor infrastructural connection to their peripheries.

Regarding climate change adaptation, UPUFS that include trees help in open space maintenance and enhance vegetation cover, improving urban micro-climate. By preventing building on risk-prone land, UPUFS help land maintenance, reduce climate change impacts of flooding, landslides and other disasters, and improve biodiversity and living conditions.

Managing livestock production and nutrient flows for low-income households in regulated open space UPUFS are strategic priorities to improve urban natural resource management. The backyard subsystem, relatively secure in its land access, already takes advantage of its nutrient surplus. The open space irrigated sub-subsystem, though less tenure-secure, likewise takes advantage of water and nutrient availability for intensified production. The insecure open space rainfed sub-subsystem, on the other hand, requires policy support to take advantage of available nutrients. The sharp difference in efficiencies of nutrient cycling and waste reuse between middle-income households with backyards and low-income high density areas must be addressed. Manure and compost depots to link livestock and crop farmers are needed.

Energy

UPUFS can help reduce the ecological foot- (and food-)print of the city and enable synergistic, cyclical processes between agriculture, domestic and industrial sectors. For example, the excess heat, cooling water or carbon dioxide from industry can support greenhouses. UPUFS capacity to conserve energy due to their proximity to markets and ability to absorb and recycle wastes should be part of energy equations and planning for both sustainable agriculture and sustainable cities.

Reuse of human waste (excreta), as described earlier, should also be a strategic priority in research and planning for better energy efficiency, as is currently being researched in Nairobi.

Human and social capital

The flow of information to UPUFS needs to be improved through official extension systems in urban areas and adapting these to their special circumstances. This is being done in some countries as they develop policies and institutions on UPUFS. Issues of urban livestock health are especially important. Local governments can also minimize health risks by adopting the WHO guidelines and offering alternative land with safer water sources (Box 16.5) as well as providing incentives (such as market channels) for safer crop production. Study results described earlier need to be widely disseminated. Good examples are materials on wastewater irrigation in west Africa (Amoah et al. 2011; Drechsel et al. 2012; FAO 2012b).

The human capital available in the community of urban farmers is demonstrated by recent developments where organizations of urban farmers have been working with local governments through stakeholder platforms (e.g. see Box 16.6).

Box 16.5 Support for urban farming in West African cities

Following a multi-stakeholder process initiated by Institut Africain de Gestion Urbaine (IAGU), the City of Cotonou and the State Ministers Council allocated 400 ha of farmland to urban and peri-urban farmers. Located on a major road about 20 km from Cotonou towards Porto-Novo, the site has shallow groundwater which can easily be lifted by treadle pump for all-season irrigation. About 1,000 farmers expressed interest and over 100 have so far moved there.

In Accra, the Ministry of Food and Agriculture pledged its support for urban agriculture in a Vision Statement and began exploring for safer irrigation water on different city sites.

In Bamako, the Yiriwaton farmers' cooperative has lobbied local government to access public land on the periphery of the city. Following a central government directive, the municipality investigated leasing 600 ha near Bamako's international airport to farmers.

In Niamey, the overall urban development plan of the city includes the intensification of irrigated and rainfed agriculture, particularly along the Niger River.

Box 16.6 Extension for urban farmers: Nairobi and Environs Food Security, Agriculture and Livestock Forum (NEFSALF)

NEFSALF is a network of Nairobi farmers that meets as a public forum hosted by a non-government organization (NGO). The Kenya government engages actively with NEFSALF, using it as an opportunity for its official extension services to reach urban farmers by providing training courses. This led to Nairobi being selected to pilot Kenya's National Agriculture and Livestock Extension Program (NALEP) 2006–2012. Over 1,000 urban farmers had been trained by 2012. The NEFSALF farmers established a representative, gender-sensitive management structure to further their interests, including their right to farm and getting access to land, and have taken part in regional and international exchanges. This form of networking encourages the development of similar structures and ways of working in other towns and cities. For example, NEFSALF is helping build capacity in both Mombasa and Dar-es-Salaam, Tanzania, where farmers' networks operate, and in 2012 NEFSALF linked with RUAF to host farmers from Freetown, Sierra Leone.

Backyard crop-livestock subsystems that efficiently manage nutrient cycling can lead to an intensive farming system of high productivity that could be a model for other farming systems, including those in densely settled highland farming systems, for example, and locations such as camps for displaced persons and refugees.

Science and technology

The lack of science and technology development for UPUFS has to be reversed, and sustainable intensification pathways developed through appropriate varietal development, better access to and uptake of urban nutrients, and intensive vertical farming using containers in low-space slum areas. Options to realize this are: including urban agricultural constraints in the agendas of NARIs, support for local research-policy platforms with regional networking, and the encouragement of action research with urban farmers' organizations.

Food safety and health risks from UPUFS must be addressed. Policy-related research needs to continue because of the variability of contaminants and the importance of urban poverty and food security where potentially risky urban food production occurs. Research must inform regulation and extension support to UPUFS.

Trade and markets

The enormous market demand for food in urban areas, especially perishables, indicates support and encouragement for UPUFS is a strategic priority. Support for intensive short-chain UPUFS, based on the backyard systems that efficiently cycle nutrients, will generate a highly productive small-scale farming system. Diversification can increasingly provide economic benefit to backyard commercializing UPUFS, while open-space farmers tend to commercial specialization. With food quality controls and support, farmers who are currently operating informally can respond to demand from all urban market outlets including supermarkets. All three subsystems are to different degrees diversifying by producing micro-nutrients for the urban market as well as household use. Additional off-farm income can also be generated by value addition enterprises related to UPUFS in all three subsystems, though this option is most readily available to backyard farmers due to their secure location. Urban extension needs to address marketing needs specific to each subsystem.

Policy and institutions

Multi-stakeholder institutions have been important innovations towards safe and sustainable urban agriculture (Dubbeling et al. 2010). Key areas for strategic policy intervention are:

- creating a positive policy environment
- acceptance of UPA as an urban land use
- secure access to vacant open spaces for UPUFS for poor and women-headed households
- enhanced productivity and economic viability of UPUFS through technical assistance, markets and credit, with priority to poor, smallholder farmers
- promoting social inclusion and gender equity
- establishment and strengthening of urban farmers' organizations
- ensuring health and environmental risks of UPUFS are reduced, through farmers' training, quality control of irrigation water and products, etc.
- including UPUFS in climate change adaptation and disaster risk reduction strategies
- emphasis on regional food systems instead of the rural-urban divide.

Table 16.8 Summary of interventions for urban and peri-urban farming system

<i>Drivers of intervention and system evolution</i>	<i>Intervention</i>	<i>Implementers</i>	<i>Implications for farming system structure and function</i>
Population, hunger and poverty	Land allocations to urban poor	Urban local governments	Space use intensification, research and development plus extension support
Natural resources and climate	Policy on waste reuse in soils	Urban local governments	Intensification, higher productivity, safety regulation
Energy	Include UPUFS in climate change plans	National, urban and regional planners	UPUFS part of urban and regional planning
Human and social capital	Farmers' participation in local government	Farmers' organizations, urban governments	Gender roles updated, urban farmers empowered
Science and technology	Research and development on healthy UPUFS and intensive space use	CGIAR, NARIs international bodies	Safe reuse of wastes in UPUFS
Trade and markets	Support for UPUFS household farms	Extension services, regulatory bodies	Increasing value addition, packaging, labelling, etc.
Policies and institutions	Set up urban food institutions	Central and urban local governments	UPUFS farmers integrated in urban food systems planning

The 'Right to Food' approach pioneered in Brazil would be a positive step in Africa, leading to land access for UPUFS for the food-insecure. A required innovation is ensuring there are departments of food or agriculture within urban authorities, as is now the case in Kampala, Nairobi, Cape Town and Addis Ababa. Such innovation, sometimes a response to the building of multi-stakeholder policy platforms, is ongoing in Ghana, Liberia, Sierra Leone and Bulawayo in Zimbabwe. These parallel the urban Food Policy Councils and similar institutional innovations in developed-country urban authorities. Equally important is the building of bottom-up market systems with farmers' networks and organizations.

System conclusions

Urban-based farming systems are of increasing importance because of the growing urban demographic in Africa. An expanding domestic market is accompanied by poorly developed rural-urban infrastructure linkages compared to other parts of the world and high urban unemployment and poverty. UPUFS supply selected commodities and support food and nutritional security for broad sections of the urban population. The lack of space for food production by the urban poor in high-density areas must continue to be addressed by farming system innovations.

UPUFS present opportunities for the intensification and modernization of the agriculture sector, due to the degree of commercialization and market access at the household farm level, especially in dairy and small-scale horticulture. They could further enhance food and nutrition security for the urban poor if supported by pro-poor policies. But the policy goals of food security and enterprise development to strengthen the urban food system need to be well articulated. And, the conceptual divide between urban food consumption and rural food production needs to be replaced by an urban and regional food system of production and consumption.

UPUFS help build resilient cities including adaptation to changing climate, through productive and sustainable use of water bodies and unused urban lands; flood protection; maintenance and increase in biodiversity; retention of prime land through intensification close to markets; urban greening; and protection against heat island effects. But most significantly, UPUFS present the opportunity for improved urban management in combination with developing a sustainable agriculture in Africa because of their capacity for cycling nutrients of which there is a surplus in urban areas.

They achieve high yields with limited space due to high availability of inputs including nutrients and labour. Further, urban demand creates a domestic market, encouraging value addition. Linkages to non-farm and off-farm activities likewise present special opportunities for sustainability through rural-urban linkages, including market and information transfers provided by the complex interactions of multi-locational households.

Current risks and challenges for UPUFS – including international market competition and insecure tenure for the open space subsystem that otherwise benefits the poor – can be addressed by the growing trend towards more coherent policies and laws at national and local level in Africa. These developments need to be sustained by continued investment in research and development that supports innovative thinking on transition to resilient cities, and includes research-to-policy linkages and institution building with a focus on farmer representation.

References

- Amoah, P., Keraita, B., Akple, M., Drechsel, P., Abaidoo R. C. and Konradsen, F. (2011) *Low Cost Options for Health Risk Reduction Where Crops are Irrigated with Polluted Water in West Africa*. IWMI Research Report Series, no. 141, Colombo, Sri Lanka.
- Battersby, J. (2011) *The State of Urban Food Insecurity in Cape Town*. Urban Food Security Series, no 11, Queen's University and AFSUN.
- Bopda, A., Brummett, R., Dury, S., Elong, P., Foto-Menbohan, S., Gockowski, J., Kana, C., Kengue, J., Ngonthe, R., Nolte, C., Soua, N., Tanawa, E., Tchouendjeu, Z. and Temple, L. (2010) 'Urban farming systems in Yaoundé: building a mosaic', in G. Prain, N.K. Karanja and D. Lee-Smith (eds) *African Urban Harvest: Agriculture in the Cities of Cameroon, Kenya and Uganda*. Springer and IDRC.
- Cofie, O., van Veenhuizen, R., de Vreede, V. and Maessen, S. (2010) 'Waste management for nutrient recovery: options and challenges for urban agriculture', *Urban Agriculture Magazine*, vol. 23, pp. 3–7.
- Cole, D. C., Lee-Smith, D. and Nasinyama, G. W. (eds) (2008) *Healthy City Harvests: Generating Evidence to Guide Policy on Urban Agriculture*. CIP/Urban Harvest and Makerere University Press.
- Crush, J., Hovorka, A. and Tevera, D. (2010) *Urban Food Production and Household Food Security in Southern African Cities*. Urban Food Security Series, no 4, Queen's University and AFSUN.
- Danso, G., Keraita, B. and Afrane, Y. (2002) *Farming Systems in Urban Agriculture, Accra, Ghana: With Special Focus on its Profitability, Wastewater Use and Added Malaria Risk*. Consultancy report submitted to FAO-Ghana office via International Water Management Institute

- David, S., Lee-Smith, D., Kyaligonza, J., Mangeni, W., Kimeze, S., Aliguma, L., Lubowa A. and Nasinyama, G. (2010) 'Changing trends in urban agriculture in Kampala', in G. Prain, N.K. Karanja and D. Lee-Smith (eds) *African Urban Harvest: Agriculture in the Cities of Cameroon, Kenya and Uganda*. Springer and IDRC.
- Denninger, M., Egero, B. and Lee-Smith, D. (1998) *Urban Food Production; A Survival Strategy of Urban Households*. Report of a Workshop on East and Southern Africa, Regional Land Management Unit (RELMA) and Mazingira Institute, Nairobi.
- Dongmo, T., Meffeja, F., Fotso, J.M. and Nolte, C. (2010) 'Crop-livestock integration in the urban farming systems of Yaounde', in G. Prain, N.K. Karanja and D. Lee-Smith (eds) *African Urban Harvest: Agriculture in the Cities of Cameroon, Kenya and Uganda*. Springer and IDRC.
- Drechsel, P. and Dongus, S. (2010) 'Dynamics and sustainability of urban agriculture: examples from Sub-Saharan Africa', *Sustainability Science*, vol. 5, no. 1, pp. 69–78.
- Drechsel, P., Graefe, S., Sonou, M. and Cofie, O.O. (2006) *Informal Irrigation in Urban West Africa: An Overview*. IWMI Research Report, no. 102, Colombo, Sri Lanka.
- Drechsel, P., Keraita, B. and Amoah, P. (2012) *Safer irrigation Practices for Reducing Vegetable Contamination in Urban Sub-Saharan Africa: An Illustrated Guide for Farmers and Extension Officers*. International Water Management Institute, Accra.
- Dubbeling, M., deZeeuw, H. and van Veenhuizen, R. (2010) *Cities, Poverty and Food: Multi-stakeholder Policy and Planning in Urban Agriculture*. Practical Action.
- Egziabher, A.G., Lee-Smith, D., Maxwell, D.G., Memon, P.A., Mougeot, L.J.A. and Sawio, C.J. (1994) *Cities Feeding People: An Examination of Urban Agriculture in East Africa*. IDRC.
- FAO (2008) *State of Food Insecurity in the World 2008: High Food Prices and Food Security – Threats and Opportunities*. FAO.
- FAO (2012a) *Growing Greener Cities in Africa: First Status Report on Urban and Peri-Urban Horticulture in Africa*. FAO.
- FAO (2012b) *On-Farm Practices for the Safe Use of Wastewater in Urban and Peri-Urban Horticulture: A Training Handbook for Farmer Field Schools*. FAO.
- Foeken, D. (2006) 'To Subsidize my Income': *Urban Farming in an East African Town*. Brill.
- Foeken, D., Sofer, M. and Mlozi, M. (2004) *Urban Agriculture in Tanzania: Issues of Sustainability*. ASC Research Report, vol. 75. ASC.
- Frayne, B., Pendleton, W., Crush, J., Acquah, B., Battersby-Lennard, J., Bras, E., Chiweza, A., Dlamini, T., Fincham, R., Kroll, F., Leduka, C., Mosha, A., Mulenga, C., Mvula, P., Pomuti, A., Raimundo, I., Rudolph, M., Ruysenaa, S., Simelane, N., Tevera, D., Tsoka, M., Tawodzera, G. and Zanamwe, L. (2010) *The State of Urban Food Insecurity in Southern Africa*. Urban Food Security Series, no. 2, Queen's University and AFSUN.
- Hovorka, A. and Lee-Smith, D. (2006) 'Gendering the urban agriculture agenda', in R. van Veenhuizen (ed.) *Cities Farming for the Future: Urban Agriculture for Green and Productive Cities*. RUAF Foundation, IDRC and IIRR.
- Karanja, N., Njenga, M., Gathuru, K., Karanja, A. and Munyao, P.M. (2010) 'Crop–livestock–waste interactions in Nakuru's urban agriculture', in G. Prain, N.K. Karanja and D. Lee-Smith (eds) *African Urban Harvest: Agriculture in the Cities of Cameroon, Kenya and Uganda*. Springer and IDRC.
- Keraita, B., Jimenez, B. and Drechsel, P. (2008) 'Extent and implications of agricultural re-use of untreated, partly treated and diluted wastewater in developing countries', *CABI Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, vol. 3, no. 58.
- Lee-Smith, D. (2010) 'Cities feeding people: an update on urban agriculture in equatorial Africa', *Environment and Urbanization*, vol. 22, no. 2, pp. 483–499.
- Lee-Smith, D. (2013) 'Which way for UPA in Africa?' *CITY*, vol. 17, pp. 69–84.
- Lee-Smith, D. and Memon, P.A. (1994), 'Urban agriculture in Kenya', in A.G. Egziabher, D. Lee-Smith, D.G. Maxwell, P.A. Memon, L.J.A. Mougeot and C.J. Sawio (eds) *Cities Feeding People: An Examination of Urban Agriculture in East Africa*. IDRC.

- Mascarenhas, O. (1999) 'Kigogo and Hananasif in Dar-es-Salaam, Tanzania: gender aspects of urbanization and natural resource management', in D. Lee-Smith (ed.) *Women Managing Resources: African Research on Gender, Urbanization and Environment*, Mazingira Institute, Nairobi, pp. 52–79.
- Mougeot, L.J.A. (2000) 'Urban agriculture: definition, presence, potentials and risks', in N. Bakker, M. Dubbeling, S. Gundel, U. Sabel-Koschela and H. de Zeeuw (eds) *Growing Cities, Growing Food: Urban Agriculture on the Policy Agenda – A Reader on Urban Agriculture*. Deutsche Stiftung für Internationale Entwicklung (DSE).
- Njenga, M., Romney, D., Karanja, N., Gathuru, K., Kimani, S., Carsan, S. and Frost, W. (2010) 'Recycling nutrients from organic wastes in Kenya's capital city', in G. Prain, N.K. Karanja and D. Lee-Smith (eds) *African Urban Harvest: Agriculture in the Cities of Cameroon, Kenya and Uganda*. Springer and IDRC.
- Prain, G. and Dubbeling, M. (2011) *Urban Agriculture: A Sustainable Solution to Alleviating Urban Poverty, Addressing the Food Crisis, and Adapting to Climate Change-Case Studies of the cities of Accra, Nairobi, Lima and Bangalore*. RUAF Foundation.
- Prain, G., Karanja, N.K. and Lee-Smith, D. (eds) (2010) *African Urban Harvest: Agriculture in the Cities of Cameroon, Kenya and Uganda*. Springer and IDRC.
- Raschid-Sally, L. and Jayakody, P. (2008) 'Drivers and characteristics of wastewater agriculture in developing countries: results from a global assessment', *IWMI Research Report*, vol. 127, Colombo, Sri Lanka.
- Thebo, A.L., Drechsel, P. and Lambin, E.F. (2014) 'Global assessment of urban and peri-urban agriculture: irrigated and rainfed croplands', *Environmental Research Letters*, vol. 9, no. 11, pp. 1–9.
- UN Inter-Agency Standing Committee (UN-IASC) (2010) *Meeting Humanitarian Challenges in Urban Areas: Assessment and Strategy*. United Nations.
- van Veenhuizen, R. (ed.) (2006) *Cities Farming for the Future – Urban Agriculture for Green and Productive Cities*. RUAF Foundation, IDRC and IIRR.
- World Health Organization (WHO) (2006) *Guidelines for the Safe Use of Wastewater, Excreta and Grey Water: Wastewater Use in Agriculture* (Volume 2). WHO.
- World Meteorological Organization (WMO) (2007) *UN Agency Calls for Urban Agriculture*. WMO Press Release, 7 December.
- Zeza, A. and Tasciotti, L. (2008) *Does Urban Agriculture Enhance Dietary Diversity? Empirical Evidence from a Sample of Developing Countries*. FAO.

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Part III

Synthesis and conclusions

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17 Farming and food systems potentials

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Key messages

- For policy purposes, Africa's 15 farming systems can be grouped into high, medium and low food security potential, representing 61, 29 and 10 per cent of Africa's agricultural population respectively.
- A range of cross-cutting issues and linkages are common across farming systems, although strategic interventions must be tailored to each farming system's context or to enhanced linkages between farming systems with benefits to market access, labour and livestock mobility, biosecurity and water conservation.
- Yield gaps vary according to farming systems. However, most crops and livestock currently have productivities around one-quarter or less of their potential. It is feasible to reduce these huge yield gaps and thereby improve food security in all farming systems.
- Intensification, diversification, increased farm size, increased off-farm income and exit from agriculture are strategies, taken singly or in combination, that households in different farming systems can implement for improvements in their livelihoods and food and nutrition security. Strategic interventions should consider the relative importance of these household strategies in different farming systems and the flow on effects.
- Extremely poor farmers (half of Africa's agricultural population) who live in farming systems with low food security potential, give their highest priority to increasing their off-farm income and to exiting from agriculture. Those in high-potential systems favour farm intensification and diversification strategies. Better-off households in all farming systems assign a high priority to farm intensification and diversification.

Summary

The potential to achieve household food and nutrition security differs in each of Africa's 15 farming systems. Understanding how to achieve the potentials for any specific farming system requires a good understanding of that particular farming system (Chapters 3–16). Typical farm households differ markedly between different farming systems. For example, average farm size varies from 0.3 ha in the forest-based system to 5.7 ha in the

perennial mixed system. Likewise herd size, livestock/crop ratios, access to agricultural services, and current and potential household food and nutrition security differ markedly across farming systems. The potential to improve national or regional food systems also varies across the 15 farming systems in Africa, due to differences in the distribution of people, land, livestock and poverty. Moreover, farming systems are functionally linked by food and labour markets, livestock and population movements, water and nutrient flows, and the spread of pests and diseases. Some improvement in food security is expected under a business-as-usual scenario. However, such small improvements would fail to achieve the targets of the Malabo Declaration, and are not acceptable. This chapter explores the potentials of farming and food systems in relation to targeted investments in seven themes: policies and institutions, markets, technologies, energy, human and social capital, natural resources and climate, and population. A key approach is to integrate the various farming and food system investments to develop sustainable intensification and diversification.

Introduction

Chapters 3 to 16 distilled the immense diversity of farming in Africa into 15 distinct farming systems and 58 subsystems, each with recognizable patterns of land use and livelihoods, and broadly similar development constraints and opportunities. This chapter draws on the results of Chapters 3–16, to consider the potential for intensification and diversification tailored to local resources and agricultural services; and the types of investments in farming systems that will improve food and farming systems performance and increase food and nutrition security. The next section synthesizes some key results on households and farming systems from Chapters 3–16 and assesses the potential for improved household food and nutrition security for each farming system.

Thereafter, we look at a policy-relevant categorization of farming systems, which is then used to explore potential improvements to national and regional food and nutrition security and to food systems. Then we highlight some key linkages between systems in relation to markets, labour, water, nutrients, livestock, fodder and biotic stress. The final section discusses key potentials for farming systems to contribute to national and regional food systems in the future. A detailed picture of African agriculture and the special contributions of particular farming systems to food systems emerges.

As an introduction to this chapter, the key characteristics of typical farm households in each farming system are contrasted in Table 17.1, and the relative distributions of people, land and livestock across the 15 farming systems are summarized in Table 17.2.

Farm households and farming systems

Notwithstanding the rapid growth of medium-sized family farms in African countries with moderate to high economic growth rates, it is widely recognized that 80–90 per cent of farms in Africa are smallholdings operating with less than 5 ha (AGRA 2016). These produce the majority of domestic food supply and agricultural exports. Average farm sizes, in terms of cultivated land, vary from 0.3 ha in the forest-based system in the Congo Basin to 5.7 ha in the commercialized perennial mixed farming system located in the southern and northwestern margins of the continent (Table 17.1). These farm sizes are quite small by global standards, and they set a limit on how much individual

Table 17.1 Summary characteristics of farm households by farming systems, 2015

Farming system	Access to agricultural resources				Access to agricultural services	Food security potential 2030
	Farm size (ha)	Herd size (TLU/hh)	Livestock/cultivated land (TLU/ha)	LGP (days)		
Maize mixed	2.1	1.9	0.9	196	Medium	High
Agropastoral	3.8	4.0	1.1	130	Low-medium	Medium
Highland perennial	0.7	1.8	2.5	267	Medium-high	High
Root and tuber crop	2.5	0.9	0.4	269	Medium	High
Cereal-root crop mixed	4.3	3.7	0.9	187	Medium-high	High
Highland mixed	1.6	3.5	2.2	183	Low-medium	Medium
Tree crop	1.4	0.6	0.4	299	High	High
Pastoral	4.7	6.0	1.3	59	Low	Low
Fish-based	1.2	10.6	8.6	194	Medium-high	Medium
Forest-based	0.3	0.2	0.7	343	Low	Low
Irrigated	1.3	2.6	1.9	47	High	High
Arid pastoral and oasis	0.3	17	67	12	Very low	Low
Perennial mixed	5.7	2.8	0.5	185	High	High
Island	0.8	na	na	225	Medium	Medium
Urban and peri-urban based	na	a	na	na	Medium-high	Medium

Note: For each column, except food security potential, the maxima and minima are indicated by darker blue and light blue shaded cells respectively. Rankings of access to agricultural services and food security potential are author estimates and are described in Chapter 2. Current access to agricultural services is rated by approximate travel time to market towns. Food security potential is estimated at the typical household level, taking into account farm size, food crop productivity and food purchase entitlements and the prospects for change in each of these factors by 2030; na not available.

household enterprises can boost their aggregate food production. Nevertheless, small farms can and sometimes are of high productivity per hectare, and are often higher than that of larger farms. As discussed later, their current productivity is generally low in Africa, and the yield gaps are extreme; so there is major scope for both intensifying the current enterprise pattern and for diversifying it by introducing new, often higher-value crop, tree or animal enterprises.

To better inform policy makers and planners, Africa's approximately 100 million farm households have been grouped into 15 farming systems. Most of these systems have been further subdivided into 58 subsystems. In 10 of the 15 farming systems, farmers manage mixed crop-livestock farms. Typical farm households also manage trees on their farms and engage in off-farm work. Indeed, the majority of African farm households, regardless of their farming system location, manage mixed systems with multiple livelihood sources.

Many farming systems in this book are named by a leading enterprise or by an enterprise group, on the basis of their prominence in the system. For instance, the fish-based farming system signifies a mixed livelihood pattern in which fish accounts for at least one-quarter of livelihoods, but households also cultivate crops and raise livestock. In the forest-based farming system, forest product income represents about one-fifth of total household income – but many crops are cultivated and contribute to household food security and livelihoods. Even pastoral farm households cultivate some cereal, pulses and vegetables, which despite the unfavourable conditions (the short and highly variable growing periods of around 60 days, diversifies diets and buffers against risk. While in most farming systems the leading enterprise contributes around one-quarter of household livelihoods (rarely more than half), most African farm households manage at least half a dozen significant enterprises.

The mixed and complex nature of African farming systems poses a major challenge for agricultural policy makers – because interactions among the farm enterprises must be considered when formulating policies and investment plans, in order to forestall the unintended consequences that inevitably occur during the implementation of broad-brush or single commodity policy solutions. Also, as in most other regions of the world, the inherent farming system complexity is further complicated by the substantial risk from climate, markets and sometimes civil disturbances. It is important to recognize that on small-scale farms, farm production decisions and household consumption decisions are highly integrated, and that the decision making of smallholder women and men seeks to optimize the benefits derived across a range of livelihood factors.

Overall, the potential to achieve household food security (Sustainable Development Goal SDG2) and poverty elimination (SDG1) within a particular timeframe (for this book, 2030), depends on a variety of factors, of which two important parameters are access to productive agricultural resources and access to agricultural services. Table 17.1 summarizes farming systems by access to productive agricultural resources (including the length of the growing period (LGP)) and access to agricultural services, notably input and produce markets. Food security potential by 2030 is also assessed for each farming system. It builds on the context for farm household decision making that is shown in Figure 1.2 (Chapter 1). To facilitate its use by policy makers, Table 17.1 lists farming systems approximately in declining order of the estimated numbers of poor and food insecure agricultural populations, with the exception of the large-scale irrigated system. The data show a great deal of variation among farming systems, underlining the diversity of farm production and household consumption conditions across Africa.

The extreme variation in the LGP will be noted, from a near-full year in the warm tropical forest-based farming system in the Congo Basin, to a mere 12 days in the arid pastoral and oasis system associated with the Sahara Desert, as well as some other hyper-arid parts of Africa. Longer growing period lengths enable higher biomass and crop productivity, as well as the production of multiple crops in a year. This spreads food production risk and avoids or shortens the ‘hunger period’. Although soil type, terrain characteristics, elevation and evaporation also influence moisture and nutrient availability for plant growth, LGP is a practical generic indicator of the potential resource productivity.

Livelihoods across the systems are supplemented by small herds of mixed species (typically cattle, goats and sometimes sheep) and small flocks of poultry. Herd sizes range from 0.2 TLU in the forest-based farming system to 17 TLU in the arid pastoral and oasis system. The ratio of livestock numbers to cultivated land area is one good indicator of the structure of the farming system. Many of these systems have a livestock/crop ratio in the range of 0.9 to 3.0 TLU/ha. In all systems there are close functional linkages

between crops and livestock, through fodder production, draught power availability, manure production, as well as being a means for buffering household risk. These systems are truly integrated crop-livestock systems.

Access to agricultural services is rated from very low to high in the different farming systems. The rating embraces a variety of public and private services, including physical and economic access to input and produce markets (indicated by travel time to major market towns), extension, technology and market information services, TV, radio and communications technology (ICT) networks, and training facilities. For any given level of physical access to markets, the quality of market services can vary markedly, depending on competition (numbers of aggregators, buyers and sellers), power asymmetries between farmers and market agents, frequency of market days, weighing and grading facilities, market information and availability of finance.

Notwithstanding the risks in forecasting the future (Rosling et al. 2018), there is an expectation of some gradual net improvement in access to resources and resource quality over the period to 2030 – notwithstanding the negative impacts of climate change, which were discussed in Chapter 2. Major improvements are anticipated in the variety and access to agricultural services, notably information and markets. With due consideration of these factors, and supplementary knowledge of the systems, the household food security potential of each farming system up until 2030 has been estimated by the authors and shown in Table 17.1. The concept of household food security includes off-farm income and household purchases of food (HLPE 2017).

Seven farming systems have good potential for household food security by 2030 in Africa. Three have a significant perennial export crop component (e.g. tea, coffee, fruit and grapes, olives and cocoa). The highland perennial farming system has a very high pressure on land resources, with farm sizes averaging less than 1 ha. However, there is medium to high access to services, and the LGP of nearly nine months enables and encourages diversification and the production of high value crops, including tea, coffee and vegetables. This system can be considered as an emerging smallholder commercialized system that offers lessons for the evolution of some other African farming systems, particularly in terms of system intensification pathways based on market integration, and integrated soil fertility management in the context of farm size limitations.

The agroindustry and commercial value chain development experiences and challenges of the perennial mixed system are also instructive for planning the development of other systems. The large-scale irrigated system has the required resources and market access to underpin a solid market-based growth trajectory. Two rainfed farming systems are considered the main engines of current (and future potential) food supply and African agricultural growth – the maize mixed and cereal-root crop mixed farming systems. They have average farm sizes of 2.1 ha and 4.3 ha respectively. Interestingly, all of these six high potential farming systems benefit from investments from substantial levels of foreign remittances. They also experience quite significant emigration to other systems, and to towns and cities.

There are other farming systems which have excellent long-term potential, such as the forest-based (currently low) and agropastoral (currently medium), but these will require substantial investment in institutions and infrastructure, including roads, in order to achieve system-wide household food security. In the case of the agropastoral system, irrigation development in selected pockets has high potential. The two other systems with low food security potential are the pastoral and the arid pastoral and oasis systems, which suffer from short and variable growing periods and very low access to agricultural services.

In 2015, the agricultural population of the 15 farming systems ranged from 4 million to 107 million (with an average of 41 million, excluding the urban and peri-urban farming system). The aggregate agricultural population represents nearly half of the African population of 1.2 billion, although there is substantial rural-urban migration especially in countries benefiting from fast economic growth. Agricultural population density varies markedly across the continent due to agroecology, infrastructure and history (Table 17.2). Nearly half of Africa's agricultural population is crowded within three farming systems (maize mixed, agropastoral and highland perennial) occupying only one-quarter of the land. In sharp contrast, two farming systems (pastoral, and arid pastoral and oasis) that spread across nearly half of the continent's area, support only 8 per cent of Africa's agricultural population.

Of the rural poor in the sub-Saharan African (SSA) part of the African continent, 72 per cent are found in the five farming systems with the greatest potential for achieving food security. The majority of the extremely poor and food insecure farm households (53 per cent) are concentrated in the top three farming systems listed in Table 17.1. The poorest 72 per cent are farming some 70 per cent of the cultivated land. Four of these five farming systems are in relatively favourable subhumid and humid climates with reasonable to good access to agricultural services, especially markets.

Table 17.2 Distribution of people, land, livestock and cultivated area across African farming systems, 2015

<i>Farming system</i>	<i>% of total continental agricultural population</i>	<i>% of total continental geographical area</i>	<i>% of total continental livestock population</i>	<i>% of total continental cultivated land</i>	<i>% of poor in SSA</i>
Maize mixed	19	12	11	16	22
Agropastoral	17	14	22	27	19
Highland perennial	11	1	6	3	11
Root and tuber crop	9	8	2	9	10.9
Cereal-root crop mixed	8	7	9	13	10
Highland mixed	8	2	8	5	6
Tree crop	5	2	1	3	6
Pastoral	7	16	13	13	5
Fish-based	4	2	13	2	4
Irrigated	8	2	7	5	3
Forest-based	2	4	0.1	0.3	3
Arid pastoral and oasis	1	30	7	0.1	1
Perennial mixed	2	1	2	4	neg.
Island	neg.	neg.	neg.	neg.	na
Urban and peri-urban	na	neg.	na	na	na

Note: Data for population, livestock, area and cultivated land are not available for the urban and peri-urban farming system due to its fragmented and geographically dispersed nature. Therefore the calculation of percentages disregards the urban and peri-urban farming system. Shaded cells indicate proportions in excess of 10 per cent.

The agropastoral, pastoral, arid pastoral and oasis, as well as the maize mixed systems each have significant livestock populations. Together, they include 59 per cent of the continental livestock population. The pastoral and the arid pastoral and oasis systems are not ranked among the top systems for their food security potential. However, they deliver critical complementary services through the provision of natural resources, and through marketed livestock income in transhumance patterns linked with neighbouring farming systems. These two systems also play a fundamental role in the political stability of the countries and regions in which they occur, and thus their agricultural prosperity. There is increasing control in these farming systems by extremist groups, and drug, people, and weapons trafficking networks. These security concerns are now drawing enormous national and international attention. Policy attention and greater investment should also be focused on the improvement of livelihoods in these farming systems, based on a much better understanding of their systems dynamics.

In the relatively food-secure forest-based farming system, nutritional security is also a priority for attention, along with the conservation of the globally important ecosystem services derived from the Congo Basin tropical rain forest. Systems-based and systems-focused policy attention is also required for the other seven farming systems.

Policy-relevant categorization of the farming systems

This book has emphasized characteristics of the farming systems relevant to policy, thus focusing on food, income security and poverty reduction. The analyses started with the farming systems that have the largest populations of poor and food insecure, farm households. This analysis of the performance of, and opportunities for, different farming systems through the lens of farm households is designed to add value to agricultural sector studies and strategies, and to contribute to policies that target investment across a huge and diverse continent. The interactions among farm enterprises, for example between cereals, legumes, livestock, trees and off-farm income, influence the response of farm households to new markets, subsidized fertilizer and other factors. Therefore, better knowledge of farming systems can enhance the development of policies for feeding the cities, generating agricultural exports, stimulating agricultural sector growth and reducing rural poverty.

Depending on the identified purpose of a given policy analysis, farming systems can be grouped in different ways. Table 17.3 groups the African farming systems according to the two main drivers of farming system function: access to resources (using agricultural productive potential as an indicator) and access to agricultural services (of which market access is one of the most important services at this stage of agricultural development).

Table 17.3 shows that most farming systems have medium to high access to agricultural resources. However, only nine have medium to high access to services, including multiple value chains which would support diversification. As access to markets improves, the proportion of produce that is sold increases. Sometimes, increased services can help intensify existing systems, but more often access to new services induces changes in production patterns and practices such as use of fertilizers or the introduction of cash crops. The existence of markets at village and national level is increasingly important to provide production incentives and improve the resilience of farms. Accordingly, there is significant scope for targeted technology spillovers among similar farming systems.

Table 17.4 groups the farming systems according to the lead enterprise. This can help policy makers to better assess both the magnitude of the potential impact of investment programmes targeted to any one enterprise, and the need to design approaches that encompass the wide diversity of farmers' livelihood sources. Plant and animal-based foods supply 91 per cent of dietary energy and 24 per cent of dietary protein respectively

Table 17.3 Characterization of African farming systems by access to resources and agricultural services

<i>Access to agricultural services (including markets)</i>	<i>Access to agricultural resources</i>			
	<i>Low</i>	<i>Low-medium</i>	<i>Medium</i>	<i>Medium-high</i>
High			Perennial mixed (12m)	Large-scale irrigated (48m) Tree crop (30m)
Medium-high			Urban and peri-urban (na)	Highland perennial (61m)
			Cereal-root crop mixed (43m)	
Medium			Maize mixed (107m)	Root and tuber crops (50m)
				Islands (2m)
Medium-low		Agropastoral (98m)	Highland mixed (45m)	
Low and Very low	Pastoral SSA (38m) Arid pastoral and oasis (8m)			Forest-based (12m)

Note: An LGP of 0–59 days was assigned to ‘low’ access to agricultural resources, 60–119 days to ‘low-medium’, 120–209 days to ‘medium’, 210–299 days to ‘medium-high’, and more than 300 days to ‘high’ access to resources. Similarly, access to markets has been rated from ‘very low’ to ‘high’ according to the travel time to the nearest major market town (Table 2.2 in Chapter 2). The agricultural population of each farming system is shown in brackets (also see Table 2.3 in Chapter 2). Farming systems names in bold font contain an agricultural population of more than 50 million.

(Chapter 1). Thus, it is no surprise that there are five cereal-led systems (maize, wheat, sorghum or millet) and that cereals play a significant role in all but two farming systems. There are three animal-led systems (cattle, sheep, goats or fish) in Africa. Perennials (coffee, cocoa, rubber, oil palm, timber, fruit trees, vines or forest) are a leading enterprise in four systems and importantly they have key supporting ecosystem and economic roles in all 15 systems. Only one system is dominated by root crops (yams, cassava), but root crops (especially cassava) play an important major role in ten other systems. Pulses and horticulture are important. They are integrated on a significant scale into all 15 systems, often allocated to low-lying areas of the farming landscape. Horticulture plays a key role, albeit a highly diverse and mixed one, in both the urban and peri-urban as well as the island systems. Horticulture is also a particularly important pathway for commercialization in the highland perennial system and some other systems. Livestock and fish play a significant role in 12 farming systems in one form or another. They are a key element of on-farm diversification, household nutrition and commercialization, especially in the case of smallholder dairy. The historical and growing diversity of production patterns on the majority of farms in most systems is a key indicator of whether the household enjoys a relatively nutritious diet or not (Herforth and Ahmed 2015; HLPE 2017).

The five cereal-led systems support a large proportion (59 per cent) of Africa's population, and more than half (57 per cent) of the livestock of Africa (Table 17.2). Cereals similarly play a significant role in another eight farming systems. The animal-led systems are dominated by cattle, although small ruminants, fish and poultry are playing increasing roles in many systems. Livestock play an important role in most African systems (except for the forest-based and tree crop system). Four systems are dominated by perennial crops and support 20 per cent of Africa's agricultural population. In reality perennials of one type or another play a key role in all African farming systems because they complement conventional crop and livestock commodities by providing items for food, fodder, fibre, medicine, construction and fuel, as well as ecosystem services for the sustainability of farming systems. These functions are particularly important for the sustainability of agropastoral, pastoral, and the arid pastoral and oasis farming systems, and for the resilience of their communities.

Table 17.4 Grouping of African farming systems by type of leading enterprise

<i>Farming system leading enterprise</i>	<i>Systems led by the enterprise (number)</i>	<i>Systems with significant role for the enterprise (number)</i>	<i>% of total agricultural population</i>	<i>% of total cultivated area</i>	<i>% of total livestock population</i>
Cereal	4.5	13	59	65	57
Root crop	1.5	10	9	9	2
Perennials	4	15	20	11	9
Livestock/fish	3	12	12	15	32
Horticulture	2	15	neg	neg	neg

Note: Cereal-led systems are maize mixed, highland mixed, cereal-root crop mixed, large-scale irrigated and agropastoral. Root crop-led systems are root and tuber crop and cereal-root crop. The cereal-root crop farming system is apportioned equally to the cereal and root crop-led categories. Perennial-led systems are tree crop, highland perennial, perennial mixed and forest-based. Livestock/fish-led systems are pastoral, fish-based, and arid pastoral and oasis. Horticulture-led systems are island, and urban and peri-urban (data unavailable). The island and urban and peri-urban systems are counted in the number of systems, but omitted in the population, land and livestock estimates for lack of data.

In relation to African food systems, the prevalence of undernourishment in SSA was approximately 21 per cent in 2015 (FAO 2017), corresponding to a Global Hunger Index for SSA of 32 and approximately 12 for north Africa (Chapter 1). Table 17.5 groups farming systems by food security potential, as described above for Table 17.1. The highland perennial system in east Africa and perennial mixed in southern Africa account for only 13 per cent of Africa's agricultural population, 7 per cent of the cultivated land and 7 per cent of the livestock (Table 17.2). The system faces severe pressure on natural resources because of high population density. As a result, it has a moderately high prevalence of extreme poverty and it experiences significant migration to nearby urban areas. There are also many pockets of emerging enterprises such as dairy. However, overall food crop productivity remains modest and poverty is prevalent due to small farm sizes. There are some similarities with the strong production and service focus on commercial tree crops in the tree crops farming system in west Africa, which has been classified as high potential.

Five additional systems have future high potential productivity (compared to the current situation). These include the engines of future agricultural growth in Africa, namely the maize mixed system in east, central and southern Africa and the cereal-root crops system in west and central Africa. Because the five future high-potential systems and the two current high productivity systems also support well over half of the agricultural population of Africa – and likely more than half of its food insecurity and poverty too – they are an important potential source of future growth, improved food security and reduced poverty. With 45 per cent of the cultivated land, and 30 per cent of African livestock (Table 17.2), these five high potential systems are worthy of much more policy and investment attention.

The five medium potential farming systems also demand greater development investment for food security, poverty reduction, equity and natural resource management reasons. Collectively, these systems contain about 29 per cent of the agricultural population, of whom about half live in extreme poverty, and occupy 34 per cent of cultivated land and 43 per cent of livestock in Africa (Table 17.2). Similarly, for reasons mentioned earlier, the pastoral (with a modest 8 per cent of the agricultural population and a low food security potential), the arid pastoral and oasis and the forest-based systems also merit increased attention, due to considerations of equity, environmental capital and sociopolitical stability.

Other policy-relevant characterizations of the 15 African farming systems could also be analysed, based on shared farming system characteristics. For instance, the pastoral, and arid pastoral and oases farming systems, which have many features in common, are linked through trade.

Table 17.5 Grouping of African farming systems into categories by food security potential by 2030

<i>Food security potential (productivity)</i>	<i>Number of farming systems</i>	<i>% of total population</i>	<i>% of total cultivated area</i>	<i>% of total livestock population</i>
High	7	61	53	38
Medium	5	29	34	43
Low	3	10	13	20

Note: See Table 17.1 for classification of farming systems' potential. The urban and peri-urban system is one of the medium potential systems but has been excluded from the population, cultivated area and livestock distributions because of lack of comparable data.

Potential benefits from better management of cross-cutting linkages between farming systems

African farming systems are interconnected, including though the historical movement of people and the economic flows of goods. Transport systems and infrastructure (road, rail and waterways) have traditionally aided trade in agricultural products and inputs. There are new and emerging linkages promoted by ICT, trade liberalization, new markets, and advances in logistics, transport systems, knowledge management and information exchange. Moreover, when they belong to the same landscape unit connected by an elevation gradient or a river system, farming systems are biophysically linked through water towers and upstream–downstream linkages in land and water use practices. Livestock and wildlife movement also contribute to the spread of weeds, pests and diseases across systems. Six of the most important linkages are considered in this section, specifically markets, labour migration, water towers, nutrient transport, livestock movements (and forages) and invasive species, and some potential improvements in linkages are identified which would contribute to improved farming systems, household food and nutrition security, and regional food systems.

Markets

In recent years markets have been the most rapidly growing linkage between different farming systems. A wide and growing variety of inputs, products, food and other merchandise is traded between farming systems. Often the trade is unregulated, yet it meets farming systems demands and it generates livelihoods for those involved in trade. In biomass constrained areas, local fodder markets are developing. These are often associated with marketable livestock products such as goats or milk. The trade in food is important for mutually exploiting the comparative advantages of different farming systems, and for reducing risk and managing vulnerabilities such as famine relief and rehabilitation. There is enormous potential to sustain and expand market linkages to benefit the people in adjacent farming systems and the wider community at large.

The potential improvements to farming and food systems from better management of market linkages include:

- cheaper inputs and reduced transaction costs – through simplified regulations, road custom control, tax systems and licensing; and through reduced barriers to the exchange of goods and entry for new traders through issuing of trade permits
- greater access to markets and increased household incomes – from the development of new physical structures (including improved availability of storage) and finance for perishable goods (including foodstuffs)
- reduced input and transport costs for produce – by improved access roads between farming systems.

Labour migration

Seasonal and permanent migration has occurred among African farming systems over many centuries. Even today, population movements from low-potential, risky environments (such as the pastoral and agropastoral farming systems in the Sahel) towards higher potential farming systems (such as the cereal-root crop mixed and humid lowland tree

crop systems), and to urban areas and overseas destinations are pronounced. There are also seasonal migration patterns by pastoralists and transhumants throughout the arid pastoral and oasis, pastoral, agropastoral and cereal-root crop mixed farming systems. Population mobility is a necessary condition of sustainable development and poverty alleviation in pastoral and arid farming systems. Conversely, farmers emigrate from densely populated high-potential farming systems, such as the highland perennial, to neighbouring medium-potential systems where more land is available. Both seasonal and permanent migration is expected to continue for the foreseeable future.

Potential improvements to farming and food systems from better management of labour linkages include:

- increased off-farm income – potentially resulting from improved population mobility and better labour market information on demands and wage rates
- empowerment of women – through better public safety and mobility for women to travel to employment
- increased farm household capital – through effective investment of remittances guided by incentives for the investment in productive resources and assets in home communities.

Water towers

Water is both an ecosystem ‘good’ and a ‘service’. As an ecosystem good it provides drinking water, irrigation and hydropower. It also provides a range of ecosystem services – provisioning, regulating, cultural and supporting services. These are often critical to poor people’s livelihoods (Millennium Ecosystem Assessment 2005).

Water management at the farm level has livelihood, hydrological and ecological impacts at watershed and basin scale. Agricultural production activities upstream have impacts on livelihood activities and ecosystem services downstream. Upstream river diversions and dams also have impacts on agricultural production, fishing and other economic activities for downstream water users. These effects are of particular relevance to the large-scale irrigated and fish-based farming systems, largely located in semi-arid or arid environments. Water use upstream can also affect ecosystems downstream and reduce their services in many ways, for example through river and groundwater depletion and consequent damage to downstream aquatic ecosystems; drainage of wetlands; and inadequate recharge of shallow aquifers important for dry season farming and water use by households outside the flood plains. The highland mixed farming system is an important water tower, and this role needs to be protected and enhanced, alongside economic and social improvements.

The resolution of conflicts between upstream and downstream water users requires effective water governance and institutional arrangements, and the equitable sharing of water between users, while maintaining adequate water flows to sustain ecological functions and critical ecosystem services to both rural and urban households. An interdisciplinary approach is essential, drawing on combined socioeconomic, hydrological, ecological and institutional analysis and data to assess and manage basin-wide welfare and ecological impacts of upstream-downstream water allocation.

Some potential improvements to farming and food systems from better management of water linkages include:

- increased water use efficiency and expanded food production – through integrated water resource management and productivity measures between and within farming systems
- an improved mix of food production – by better water allocation through the establishment of water accounting systems
- lower food production costs and food prices – through increased productivity resulting from improved water governance systems, and from the development of institutions that encourage the formation of water user associations to better manage water resources.

Nutrients for cropping

Urban areas produce enormous nutrient surpluses. However, these nutrients are not generally used in an ecologically sound manner by the surrounding farming systems. Millions of tonnes of solid waste are produced annually in African urban areas. Around 70 per cent of this waste is biodegradable and, if recovered, could be used either as livestock feed or for compost making. There are successful cases of urban waste being used for rural farming systems (Karanja et al. 2010) and in urban and peri-urban farming, where some small-scale, backyard crop-livestock farmers utilize cities' solid waste.

Nutrient movement is also linked to livestock migration and exports. Soils are enriched near settlements because of the daily movements of livestock, and the deposition of dung around villages. A net nutrient flux also occurs with the net export of meat to more densely populated areas, through contacts between farmers and livestock owners. So far, nutrient transfer between cities and farming systems has not been part of the framework of policy or planning in either the urban and agriculture sectors (Karanja et al. 2010; Lee-Smith 2010).

There are a number of nutrient-based potential improvements to food and nutrition security that could be supported:

- improved sustainability of food production – from increased compost and soil nutrient availability to rural farming systems through improved logistical systems for the reuse of nutrients from urban and peri-urban wastes
- expanded food production and reduced prices – through the increased supply of fertilizers to farming systems; this could result from improved recovery of phosphorous and nitrogen from urban wastes. This has been documented to be technically and economically feasible and desirable
- expanded and sustained fish production in coastal fisheries – through better management of the flows of agricultural nutrients from hinterland landscapes.

Livestock movements

Many animal species migrate within and between African farming systems. Cattle migrate seasonally between the pastoral system in the Sahel and the more humid agropastoral and cereal-root crop mixed farming systems to the south, a migration known as transhumance (Ayantunde et al. 2011). Camels migrate from the arid pastoral and oasis system, sporadically, to farming systems to the south. Other livestock species migrate over shorter distances within farming systems.

The migratory nature of the pastoral system of production often creates opportunities for mutually beneficial exchange relationships between pastoralists and crop

farmers. The exchanges of grain, crop residues and water for manure have linked crop and livestock production for generations in the Sahel. Similar but shorter migration patterns occur in the Horn of Africa. However, livestock does not migrate across farming system boundaries in southern Africa. Animal production in migratory herds is higher than that of resident livestock, but long-distance migration of livestock can result in serious conflicts between pastoralists and sedentary farmers. It can also enhance the transmission of animal diseases. Fenced ranching and veterinary boundaries slow the spread of animal disease.

A variety of wild animal and bird species also migrate over long distances crossing farming system boundaries, notably between pastoral and agropastoral systems. Nowadays, the long-distance migration of large mammalian herbivores in Africa including wildebeest, zebra and the white-eared kob, is restricted to the eastern part of the continent. The development of agriculture, and the consequent land use changes, are increasingly reducing crucial wildlife habitat, and they are seriously limiting animal migration and movement between farming systems.

Migratory locusts and weaverbirds, notably the red headed Quelea (*Quelea quelea*), travel across farming system boundaries. They cause significant damage to crops, including sorghum. In some cases, early warning systems have been put in place to detect insect development at an early stage to allow preventive measures. Migratory birds and mammals can be major agents for spreading animal and human diseases. The need for better insight into the role of these migratory hosts in the transmission of disease and its economic impact was highlighted after recent concern over the impact of avian influenza on human and animal health.

Better management of livestock linkages could lead to potential improvements in farming and food systems, such as:

- simplified management of livestock and farming systems – systematic documentation of the positive and negative effects of livestock and wild animal movement across systems can inform the formulation of better regulations and policies
- reduced livestock losses from disease – better veterinary inspection services for trans-humant livestock before migration can reduce disease transmission
- increased livestock productivity – better regulatory frameworks will encourage livestock movements that will maximize the positive benefits and minimize the negative impacts.

Weeds, pests, diseases and invasive species

Striga hermonthica is a frequent parasitic weed of several cereals. It is spreading across many African farming systems. It is a significant constraint, especially in areas where the continuous mono-cropping of sorghum, millet or maize is common. In west Africa, yield losses due to *Striga* can sometimes reach 100 per cent. It has been estimated that *Striga* threatens grain production on 44 million ha of land in Africa, representing a potential economic loss of US\$3–7 billion per year.

The forested parts of farming systems often include areas of largely undisturbed ecosystems, without weed (or pest and disease) problems. The status and age of a post-disturbance forest affects the risk of weed incursion into cropped fields. The distance to the nearest road or previously cleared field and the season, are possibly even more important. Wind-dispersed species can establish in new clearings, such as *Chromolaena odorata*, an invasive exotic of the *Asteraceae* family (that flowers in the dry season and produces very small wind-dispersed seeds).

Weeds that are not wind dispersed may be carried by animals (stuck to fur or feathers), dragged with the soil attached to the shoes of people moving between clearings, or they may be a contaminant in seed lots used to crop new clearings. Typical forest crops such as plantain, banana, cassava, yam, cocoyam and taro grow rather slowly in the early stages. Thus, they have little if any competitive ability against weeds. Poor knowledge about weed control in general, and insufficient knowledge about the damage caused by early weed competition on practically every crop, leads to heavy infestations and weed seed production, and to seed dispersal through human activity and other vectors.

In African farming systems, the combined losses due to insect pests are estimated to be as high as 50 to 80 per cent of yields. Head miner on sorghum and millet is found throughout the Sahelian zone from Senegal, Mali, Burkina Faso and Niger to Chad, and wind-dispersed vectors are particularly critical.

Plantain and banana, which are found in many farming systems, suffer from wind-dispersed pests and diseases. Black sigatoka (*Mycosphaerella fijiensis*), introduced to Africa, has today spread across most of the plantain and banana growing countries, mainly through wind and water dispersal. A similar case is *Phytophthora megakarya*, the fungus causing black pod disease on cocoa (*Theobroma cacao*). It is spreading across the tree crop system in west and central Africa and displacing the less virulent and damaging *Phytophthora palmivora*.

In the forest-based farming system, the banana aphid (*Pentalonia nigronervosa*) that carries the banana bunchy top virus, is spreading along feeder and logging roads in the forested parts of the Congo basin. Rapid infestation of large areas is caused by wind dispersal and from the sales of aphid-infested suckers, banana bunches and banana leaves. The nematode *Radopholus similis*, an introduced species that damages plantain and banana roots, often causes major yield losses through the toppling of the plants. The nematode does not survive long phases in the soil without a host, yet it has spread across most of the African banana-producing countries, most likely via contaminated suckers.

Diseases are a major constraint to livestock production, particularly for poor livestock-keepers with few animals. Major diseases affecting small ruminants include *pestes des petits ruminants* (PPR) and contagious caprine pleuropneumonia (CCPP). Newcastle disease affects village poultry. Trypanosomiasis, contagious bovine pleuropneumonia (CBPP), brucellosis, anthrax, and foot and mouth disease (FMD) affect cattle. Not only do diseases limit production, but FMD, CBPP and CCPP also prevent smallholders from participating in export markets for livestock products. The reduced role of the state in the provision of veterinary services, and the inability of the private sector to fill the void, have led to a resurgence of endemic animal diseases and to reduced livestock productivity in many parts of Africa.

There are a number of potential ways to improve farming system health, and positively impact on food and nutrition security, which could be supported:

- reduced variability in food production – by improved weed and pest surveillance mechanisms, and combined advisory services and alerts to neighbouring areas
- improved household food and nutrition security – through farmer and pastoralist awareness and education programmes on pests, weeds and animal diseases using ICT systems
- increased stability of crop and livestock productivity – resulting from the development of national frameworks and regional cooperation for managing the threat of weeds, pests, diseases and invasive species.

Upgrading farming systems to benefit household food and nutrition security, and national and regional food systems

This section explores important potential upgrades to farming systems that will contribute to improved household food and nutrition security, and strengthened national and regional food systems, by 2030. They provide a basis for discussion of the elements of food security and food system strategies that will be taken up in Chapter 18. The context is national and regional food systems. However, the emphasis lies on the food and nutrition security of rural dwellers, especially farm households (HLPE 2017), which comprise the majority of the under- and malnourished population in Africa. The following sub-sections are structured around the seven themes of farming system change used in earlier chapters, but in reverse order from previous chapters.

Policies and institutions

There is a plethora of policies and institutions which influence the decisions of farm households, the resulting patterns of crops, livestock, fish and trees, and therefore, the directions of farming systems development. These shape food production and diversity of foods, and household food and nutrition security.

African farm households account for nearly half of the African food consumers, and they produce more than 80 per cent of the food supply in Africa. Thus, the production and consumption behaviour of farm households fundamentally shapes national and regional food systems, and greatly determines national food and nutrition security. It follows that there is the potential to improve food and nutrition security by 2030 using selected improvements in the policy and institutional enabling conditions for farm household engagement. In fact, the redesign of institutional arrangements is now viewed as one of the most important sources of improved farming and food system potential.

Many African countries are considered to be at tipping points to sustained economic growth (as discussed in Chapter 1). Thus, there are many new opportunities opening up for farmers. There is great potential for the further intensification of existing commodities, through improved germplasm and better enterprise management (Fischer et al. 2014). Even more importantly, there is great potential for improved farm management and on-farm diversification by incorporating new crops, trees and livestock to increase food production and income (Chapters 3–16). Over the coming years, some farmers will have opportunities to engage with many novel sources of livelihoods, for example on-farm value-adding, bioenergy crops (Langeveld et al. 2013), rhizobia (Howieson and Dilworth 2016) and payments for ecosystem services (including carbon).

A farming systems approach is required to understand the interactions between the existing land and water resources, and plant and animal production. Such an approach is essential to assess upgrades to farming systems, especially the introduction and ‘system fit’ of new or novel farm activities, as farmers respond to emerging opportunities. The mainstreaming of the farming systems approach – accompanied by adequate capacity for participatory farm, forest and ecosystem analysis – supports the formulation of policies targeted to specific farming systems that are fine-tuned to the intra-system interactions between system components (water, crops, livestock, trees, forest and common property resources such as range and water). Bearing in mind the massive gaps between existing and potential productivities of crops and livestock (often 70 to 80 per cent of potential production),

there is great potential for carefully selected policies that will contribute to the reduction of yield gaps, and improved household food and nutrition security.

The mainstreaming of a farming systems approach by policy makers and planners also enables the implementation of local area-based approaches. The mechanisms and institutions for farming system development (with both intensification and diversification) can be merged with those for rural transformation. A pilot application in Ethiopia identified investment opportunities in each farming system of the country, providing knowledge for the National Agricultural Investment Plan (Amede et al. 2017). As noted in Chapter 1, there are strong linkages and economic multipliers between the smallholder economy and the rural non-farm economy. There are large potential benefits from tapping into, and managing, the multipliers between the two sub-sectors.

The establishment of national working groups for each farming system has the potential for great impact on food security. For example, Ghana could establish two farming system working groups, one for the root and tuber crops system and another for the cereal-root crop mixed system. Such working groups would foster learning across multiple stakeholders (from public, private, civil society and farmer groups), and could coordinate the collection, analysis and communication of farming system information. This would add value to administrative statistics by blending data on many different types of agricultural production. Some farming systems cover populations in up to a couple of dozen countries. Thus, regional working groups that are endorsed and supported by sub-regional or regional organizations would also be valuable. For example, a regional cereal-root crop mixed farming system group might be supported by West and Central Africa Council for Agricultural Research (CORAF/WECARD).

The mainstreaming of the farming system approach will link stakeholders, including researchers, businesses and policy makers into a systems framework. It will ensure that research and development (R&D) is underpinned by sound participatory engagements with farm women and men and local entrepreneurs. Such farming system working groups will be able to identify policy conflicts which limit farming and food system improvements, and determine the assortment of incentives which impinge upon farm household decision making. Often, contrasting policies create conflicts between incentives for farmers, leading to unintended consequences and sometimes unsustainable development pathways.

Rural smallholder households pursue the following five main strategies to improve their livelihoods and their household food security or to escape poverty: intensification of existing production and processing patterns; diversification of production and processing patterns; expanded farm, enterprise or herd size; increased off-farm income, both agricultural and non-agricultural; and complete (family) exit from the particular farming system (Chapter 1; Dixon et al. 2001). These same strategies are also deployed by less poor farm households that are pursuing improved livelihoods and incomes. The relative potential of these strategies to reduce poverty in the poorest segments of rural populations in each farming system was assessed by a group of experts for each farming system (Table 17.6).

Policy making needs to consider the different household strategies for food security or escape from poverty, in order to determine the appropriate mix of incentives and drivers to shape positive and impactful change in each farming system. Strategic interventions should carefully consider the relative importance of these household strategies in different farming systems, and the flow-on effects.

In the large majority of farming systems, the potential is high for intensification and increased productivity to contribute to the betterment of livelihoods. This emphasizes the

Table 17.6 Relative importance of household strategies for escape from extreme poverty, 2015

<i>Farming systems</i>	<i>Intensification</i>	<i>Diversification</i>	<i>Increased farm size</i>	<i>Increased off-farm income</i>	<i>Exit from agriculture</i>
Maize mixed	2.5	3	1	2.5	1
Agropastoral	2	1.5	0.5	3	3
Highland perennial	1	2	0	3	4
Root and tuber crop	3	3	1.5	1.5	1
Cereal-root crop	3	2	1	2	2
Highland mixed	3	2	1	1	3
Tree crop	1	1	0	8	0
Pastoral	1	1	0	3	5
Fish-based	2	3	0	3	2
Irrigated	5	2	0.5	1.5	1
Forest-based	1	2	1.5	2.5	3
Arid pastoral and oasis	0.5	1	0	3.5	5
Perennial mixed	3	3	1.5	1.5	1
Island	2	2.5	1	1.5	3
Urban and peri-urban	2	2	4	1	1

Source: Estimates by the farming systems chapter authors for SSA portions of farming systems.

role of science and technology. Yield gaps are large in most farming systems, but technologies and approaches for more productive and sustainable land management options are available. This pathway is particularly promising in the large-scale irrigated system, the tree crop and the land-abundant cereal-root crop farming system. Technology-based improvements are also crucial in a number of other systems including the urban and peri-urban, agropastoral, root and tuber, highland mixed and pastoral farming systems. Across all farming systems, there was a noticeable increase over the period from 2000 to 2015 in the priority assigned by farmers to system intensification, which naturally requires effective technologies, skills, markets and finance.

The few systems where intensification may not lead to significant livelihood improvement of poverty reduction include the arid pastoral and oasis, highland perennial and the fish-based farming systems. The reasons for this differ according to systems. In the densely populated highland perennial farming system, the lack of access to assets, especially land, constrains the potential impact of intensification in lifting farmers above the poverty line. Returns from improved technology can contribute to addressing household food insecurity, but they are too small for rainfed crop production alone to lift a significant number of farm households out of poverty (Harris and Orr 2013).

Diversification will be an important strategy in many farming systems, with large potential for livelihood improvement, including the maize mixed, fish-based, agropastoral, root and tuber, and forest-based farming systems. To achieve the potential for on-farm diversification, effective policy incentives for diversification with new crops, trees and livestock need to be complemented by farmer training and new value chains to deliver appropriate and affordable inputs to farmers and link production with markets. Crop-tree-livestock

systems of diversification hold particular potential for smallholder farm families to optimize resource flows and other positive interactions among enterprises, and to maximize the land equivalent ratio on their farms.¹

Increased farm size is no longer perceived as an important or feasible pathway out of poverty in any farming system for the vast majority of poor families, relative to other pathways. There has been a drastic reduction of the rating for this poverty escape pathway across the African continent in all farming systems since the late 2000s. This has been caused by the development of a critical shortage of available land for production expansion in most farming systems in recent years. It highlights the urgent need for a shift towards managed intensification and diversification on very small farms. However, some potential for increased farm size does still exist in three farming systems that have relatively lower population densities, namely the root and tuber crop, cereal-root crop and forest-based farming systems. There are also some opportunities for agricultural expansion on undeveloped land in urban and peri-urban settings.

The off-farm income pathway has a key role to play in household economic growth by generating returns that can be reinvested into the farm, and also used for complementing a shortage of on-farm production to meet household consumption needs. The major sources of off-farm income are off-farm employment in the neighbourhood, seasonal migration and remittances. This pathway is rated highest in farming systems that are relatively well integrated with the market, such as the arid pastoral and oasis, highland perennial, fish-based and maize mixed farming systems.

Exit from agriculture is often very risky and may lead to greater poverty for unskilled farmers. The exception is the small proportion of educated and skilled farmers with social connections that allow them to integrate into other labour markets, particularly in urban areas. This pathway may therefore be most important in farming systems with high inherent natural risk, remoteness, immediate lack of economic opportunities, and untenable small farm size or landlessness. Such systems include the arid pastoral and oasis, highland perennial, highland mixed, pastoral and forest-based. Farmers facing such vulnerabilities often require a new set of skills that are radically different from the agricultural-based livelihoods that they and their relatives have pursued for generations. This underscores the important role of public institutions and policies that favour education, technical training and job creation to enhance the opportunities for a successful exit from farming into higher income professions.

Some conclusions are possible from these analyses of household strategies. First, there are significant differences between farming systems (Table 17.6), and between the extremely poor and the less poor, that call for differentiation and targeting in policy making. For instance, if responsiveness of crops to fertilizer is greater in the maize mixed system, and there are more functional markets compared with those in the agropastoral system, then input subsidies might be effective in the maize mixed system while having limited impact in the agropastoral system.

Moreover, the different strategies for poverty reduction by the extremely poor relative to the less poor suggest that policy options intended to simultaneously reduce poverty and increase rural income might differ. Second, off-farm income is a growing share of smallholder livelihoods and rural (and regional) labour markets. It needs to be strengthened, and there are also opportunities for policies that would provide greater incentives for the investment of remittances in farm improvement. Third, an increased farm size or herd size will account for less than 20 per cent of poverty reduction or income growth in all farming systems, except in the tree crop and the urban and peri-urban systems.

The conclusion from much of the earlier analysis is that smallholder farming productivity can, and is expected to, increase, and that large-scale commercial farming is not the

Table 17.7 Relative importance of pathways for poverty escape for poor households in 2015, categorized by farming system food security potential

<i>Farming system food security potential</i>	<i>Intensification</i>	<i>Diversification</i>	<i>Increased farm size</i>	<i>Increased off- farm income</i>	<i>Exit from agriculture</i>
High	2.5	2.5	2.0	1.7	1.4
Medium	1.5	2.5	2.1	1.9	2.0
Low	3.3	1.6	2.0	1.6	1.6

Source: Based on chapter authors' estimates, with aggregation weighted by farming system agricultural populations.

prime solution to growth, food security or poverty reduction. Fourth, the massive yield gaps across all systems for major food commodities are a concern and an opportunity for intensification to increase productivity with existing resources – accounting for 15–33 per cent of future poverty reduction (Table 17.7). This is principally related to strengthening and expanding the reach of existing services.

Once household food and income security is assured, farm households often pursue crop and livestock diversification strategies – at this stage of economic development, poverty reduction strategies for the poor using diversification will vary widely across farming systems (Table 17.6).

Trade and markets

Because transport infrastructure and roads are projected to expand very rapidly in Africa in the 2020s, there are many farming systems for which physical access to markets will improve dramatically, at least for their main products. A real issue is the low rate of return to the capital which could be invested in new value chain capacity to support diversification into high value products and resilient enterprises, especially in remote areas. The provision of other agricultural services will also be an important aspect. Overall, there is good potential for improved food security from improved access to agricultural services.

The key growth potential in food trade and markets lies in the rapidly expanding domestic and regional markets within Africa. Development of these can reduce the requirements for foreign exchange to import food, especially in periods of global shortage of supply, and it will improve the diversity of urban food supplies and increase farm income. There is great potential to increase the efficiency of food value chains, ideally opening up opportunities for youth entrepreneurs. On-farm diversification can improve diet diversity and reduce rural malnutrition, and create non-farm employment and economic growth in new input-, produce- and processing- chains associated with new crops.

There is growing potential for inter-regional trade in food crops which will strengthen African food systems, and the linkages back to high potential farming systems will boost farm income in those systems as well. Both domestic and regional value chains can be stimulated by the Growth Corridor approaches which are now being implemented in many African countries, for example in southern Tanzania and northern Mozambique in the maize mixed farming systems, and in northern Ghana's cereal-root and tuber crops farming systems.

A specific potential is the employment of youth, and in particular equipping youth with the skills and resources for agribusiness startups in rural areas. As noted earlier, Africa

has a demographic youth bulge which, if harnessed effectively in rural areas, is an asset to stimulate farming systems development and non-farm rural economic growth.

Over the 2020s it is expected that the role of the private sector will strengthen in high potential and some medium potential farming systems. Opportunities will emerge for blended public and private sector investments in agricultural services of various types, notably information sharing and financial services for savings and lending.

The contrast between the value chain requirements for intensification and diversification is worth noting. Intensification generally implies an expansion of existing chains and, where entry barriers to the chains are not too great, increased competition. However, on-farm diversification to new crops and livestock generally requires the development of new value chains to handle produce, and sometimes new seed or other special inputs might be required, for example for export or bioenergy crops.

There is another important aspect to value chain development: new technologies and innovations need to be made available to millions or tens of millions of farmers. For example, new seeds and new machinery are needed – along with complementary information, financing services and effective institutional arrangements. Some aspects are discussed in the next section.

Science and technology

The adoption and mainstreaming of innovative systems approaches will contribute greatly to improved food systems and food and nutrition security. Innovations are being generated at an increasing rate, although many are most immediately useful in specific farming systems. Rapid progress is being made in genomics and food crop yield potential (although not always up to the required 1.3 per cent per annum – Fischer et al. 2014), other biotechnologies such as rhizobia (Howieson and Dilworth 2016), biofertilizers, remote sensing, precision agriculture and behavioural science. The core issue in Africa is the uneven distribution of agricultural science capacity across countries and farming systems, and insufficient research investment – current expenditure of approximately 0.5 per cent of GADP compared with a common target of around 1 per cent of GADP, depending on country circumstances. The lack of systems research is a major constraint to the development of integrated, adaptive innovations which respond to the complex sets of challenges that include climate variability and change.

Whereas agricultural production has kept pace with population growth in Africa (IFAD 2010), the concern is that a considerable proportion of the increased production has been derived from the expansion of cultivated area rather than increases in land productivity. Also, this growth has not generated the surpluses to boost household food security or incomes. Greater improvement in sustainable productivity is needed to meet the rising demand for food, feed, fuel and fibre on the existing footprint – with some expansion into fertile lands where it can be sustainably managed. Up to 2030, increasing productivity will be central to containing food prices despite rising resource constraints, and it will be a key factor in reducing global food insecurity.

Productivity gains in the medium term may come primarily from reducing the productivity gap. Across African farming systems, the gaps between actual productivity in 2015 and potential production with existing technologies are, on average, in the order of 80 per cent (that is, average yields of about 20 per cent of estimated potential yields). There are many reasons for these substantial yield gaps. Widespread occurrence of soils with low nutrient status and limited application of crop nutrients, inadequate pest management,

lack of quality seed, and above all, lack of markets and weak incentives for intensification result in poor field and farm management. Similarly, large livestock performance gaps exist for analogous reasons. The performance gaps tend to be smaller where production incentives and management intensity are somewhat better, which is often where there are good production and economic conditions such as for export or cash crops.

Overall, there is massive scope for increasing crop, tree and livestock productivity with current technologies in most farming systems. The higher food security potential systems tend to have higher than average yield gaps, which is some concern. For example, the yield gaps in the large-scale irrigated and highland perennial systems are 76 per cent and 82 per cent, respectively. In contrast, the commercialized perennial mixed system has a yield gap of 54 per cent.

In the forest-based farming system, characterized by good natural resource endowment and subsistence-oriented crops, the yields have been low and stagnant over time. This is associated with low research investment in technology development. Growth in African food production is half or lower than population growth rates, and it tends to be compensated through food imports. van Ittersum et al. (2016) estimated that meeting future SSA cereal demand on the existing production area will not be feasible by yield gap closure alone. It will require other more complex changes to sustainable intensification, including increased cropping intensity and expanded irrigated production area. Current population growth scenarios in the Congo Basin are expected to result in a significant reduction in fallow periods, lower soil fertility and less production of ecosystem goods and services. Without yield-increasing innovations, higher land use intensity and frequency may lead to lower system performance, food insecurity, out-migration and permanent conversion to other less sustainable farming systems. Food production gains resulting from the expansion of agriculture need to be carefully weighed against the loss of ecosystem services associated with deforestation.

There are large and enduring potential benefits to food and nutrition security from improvements to soil health. Degradation can be stemmed by appropriate practices such as conservation agriculture, and by assisting farmers to improve soil fertility by combining organic and inorganic nutrient sources. Depending on their access to labour, cash, livestock, trees and credit, these practices would have high potential for impact. Inevitably, such an approach must be tailored to local farming system conditions, and it requires sensitivity in understanding how farmers adapt their systems over time. The role of perennials in many farming systems will also contribute to sustainable and resilient intensification. For example, the agropastoral systems of the Sahel could benefit enormously from further integration of useful trees in agroforestry parklands. Recently, the Africa Union has called for a massive effort to reach every farm household in the drylands with the ability to practise farmer-managed natural regeneration of trees on farmlands.

Human and social capital, knowledge sharing and gender equity

Education and farmer training are essential to farming and food system potential. However, consideration could be given to the inclusion of systems thinking, management skills and innovation practices in the curricula of schools, farmer training centres and universities. Because of emerging opportunities in agriculture, the concept of lifelong learning is appropriate and would contribute to substantial improvements in food and nutrition security.

In addition to education, the role and potential for increased social capital to contribute to farming and food systems is being recognized. It can contribute in many ways, including farmer-to-farmer learning; enhanced local innovation; group action for the

management of common property resources (for example, grazing and water points); and group marketing (to reduce transport and transaction costs and increase the negotiating power of farmers). Innovation platforms are an important mechanism for building the social capital of multiple local stakeholders, including farmers, NGOs, traders, extension and researchers. The systematic establishment of innovation platforms would be a major contribution to farming and food systems.

Similarly, information sharing, and the empowerment of women and marginalized groups, has great potential to increase food and nutrition security, for multiple reasons (Lilja et al. 2010). These can have a significant effect on food security potential, especially in a digital era through the use of big data, remote sensing and artificial intelligence to provide and share information.

Rural energy, especially renewables

Energy is an essential input to agriculture, and especially to intensification and (most) diversification of farming systems. In well-serviced, higher population density farming systems, village electrification will lead to many improvements in farm and household management of production and consumption, with direct benefits to food and nutrition security. In farming systems with sparse services, such as the majority of the agropastoral and pastoral systems, local sources of energy will have more impact. Solar and wind power will be two important sources of decentralized renewable power in the period to 2030, using readily available technologies with declining investment costs. As noted earlier, the tropics have a natural comparative advantage in biomass production, and there is great potential for the development of biomass energy cropping and biofuel production in all of the high and medium potential farming systems.

Natural resource management

The predominant land use in the African landscape is grassland, which underpins the livestock systems. These are a major contributor to livelihoods and household food security and have significant opportunity for future growth. In addition to food security benefits, well-managed grasslands maintain biodiversity, sequester carbon and produce many other environmental benefits.

Second to grasslands, forests still cover a large area of Africa. Unfortunately, forest areas are rapidly contracting and protected areas are under severe human pressure. The forest-based farming system has diminished in extent since 2000, transitioning in some regions to tree crop systems and on-farm timber production. Forests provide key ecosystem services, support the commercial logging industry and they may strengthen household food security and livelihoods. In addition to the forest-based system, there is extensive secondary forest in the tree crop and the root and tuber crop systems in west Africa, as well as in the maize mixed system in central Africa and throughout several of the humid, sub-humid and semi-arid farming systems. Effective policies for conserving these forest systems' significant plant and animal diversity and maintaining the provision of ecosystem services are needed. Managed buffer zones at the agriculture/forest interface offer a range of sustained benefits to local communities. The artisanal fish-based system is often adjacent to forest and grassland, and encompasses 41 per cent of inland water bodies.

The potential of farming systems and households depends on access to productive resources and how sustainably these resources are used. Africa-wide, approximately

two-thirds of farm household livelihoods are derived from annual or perennial crops and about one-third from livestock. Although the proportion of total area which is cultivated (8.3 per cent) is currently limited, there is potential for expansion of rainfed cropping in some farming systems. A significant portion of land is dedicated to grazing and protected areas, and of course a large proportion is arid, for example, the Sahara and Kalahari Deserts. Irrigated areas currently account for only a tiny proportion of land use, but the potential for expansion is very large, partly through surface waters but principally from underground water reserves. Naturally, fish production depends on lakes, rivers and oceans, with significant potential for expansion. The most intensively cultivated farming systems are the perennial mixed (33 per cent), large-scale irrigated (25 per cent), the highland mixed (24 per cent) and the highland perennial system (20 per cent).

There is considerable variation in the land quality and the level of inputs across the majority of African agriculture. van Velthuisen (2015, unpublished data) and van Velthuisen et al. (2013) estimated that under low input conditions, such as those prevailing for most African farms in 2015, only 20 per cent of cultivated land would be regarded as prime quality and about 60 per cent as good quality (nearly 20 per cent is poor). However, under a future scenario of high input levels, 38 per cent would be regarded as prime quality and 54 per cent as good quality. The systems with the highest proportion of prime quality land available for low input, traditional management farming include the cereal-root crop mixed system, the maize mixed, agropastoral and perennial mixed systems. At the other extreme, the arid pastoral and oasis, irrigated, highland mixed and pastoral systems have the largest area of poor quality land. Increasing management intensity has the greatest impact on expanding the combined proportion of good and prime quality land in the pastoral, irrigated, fish-based and tree crop systems, but relatively little impact on the forest-based, perennial mixed and arid pastoral and oasis systems.

The cereal-root crop mixed farming system is the system with the largest area of unused land suitable for agriculture. Two-thirds of its area (600 million ha) could technically be cultivated, but currently less than 10 per cent of this is cropped. The World Bank (2009) considered the Guinea Savannah zone, where this system is found, to be one of the largest underused agricultural land reserves in the world. The cereal-root crop mixed farming system has one of the highest agricultural growth trajectories in Africa, through the expansion of cropping area, greater mechanization, and higher crop and livestock productivity.

Irrigation is often promoted in agricultural development plans and policies because of its important role in the Asian Green Revolution and subsequent agricultural development. Today, in terms of regional food security, irrigation in SSA agriculture is relatively marginal because of the small area covered, although it is of critical importance in the drier north African systems. For the future, water remains an important, but as yet untapped resource for the majority of the region. The current irrigated area represents only 20 per cent of the irrigation potential estimated by FAO (Faurès and Santini 2008). Furthermore, there are massive shallow aquifers which could, with investment and sustainable management, transform many African rainfed farming systems.

Because of low productivity, human and livestock population growth are placing significant pressure on agricultural resources. There is, however, potential to reduce the pressure (and improve food security) through appropriate intensification and diversification, especially if combined with policies to encourage migration to other sectors. As noted earlier, there is a surge in the number of mid-sized farms of 5–100 ha in quite a few countries (AGRA 2016). Table 17.8 shows that the highest pressure on resources occurs in the farming systems with current high potential for improved food security.

Table 17.8 Pressure on resources categorized by farming system food security potential

<i>Farming system food security potential (productivity)</i>	<i>Human population density (p/ha)</i>	<i>Human pressure on cultivated land (p/ha); mean farm size in brackets (ha)</i>	<i>Livestock density (TLU/ha)</i>	<i>Human pressure on livestock herds (p/TLU); herd sizes in brackets (TLU)</i>
High	0.4	2.6 (2.1)	0.1	2.8 (2.0)
Medium	0.3	1.9 (2.9)	0.2	1.2 (4.7)
Low	0.04	1.7 (3.3)	0.04	0.9 (6.3)

Note: See Table 17.1 for classification of farming systems by food security potential in 2030. Human population density refers to agricultural population. The urban and peri-urban and island systems were excluded because of lack of comparable data.

In densely populated farming systems average farm sizes are decreasing and the age-old practice of fallowing has practically disappeared, with the consequence of declining soil fertility and land degradation. Fortunately, there are well-known practices and enabling institutions which can restore degraded land, improve soil fertility and increase productivity. Thus, the potential exists for sustainable land management and improved food security.

Conclusions

Under a business-as-usual scenario, some improvements in African food and nutrition security will occur. For example, yield increases with management intensification are widely documented throughout the various farming systems. However, high rural poverty levels and increasing climatic variability mean that households face very high (and increasing) levels of risk. This limits their investment capacity, their returns on input investments and their ability to innovate. This dire situation is complicated for households that also face food insecurity. Such risk levels drive farmers to remain engaged in subsistence farming and focused on the production of staple crops. However, the risk levels vary across crops and between livestock species, and this can inform more sustainable, integrated and food-secure farming systems.

In this chapter, the contrasts between farming systems have been documented, with some clear indications of where potential improvements in food security and food systems may be sought.

The full potentials of African farming and food systems, as envisaged in the Malabo Declaration and the Sustainable Development Goals, will not be achieved without specific development actions. Targeted interventions can enhance market, labour, water, livestock and other linkages between different farming systems. These should include the explicit consideration of efficiencies, equity and comparative advantage.

A vision of productive, food-secure and profitable farming and food systems needs to focus on intensification and diversification based on multifunctional farming systems and sustainable landscapes. This implies improved production of food, as well as delivery of other beneficial services in the form of rural development and ecosystem services.

There are trade-offs between the productivity and livelihood benefits of farming and the provision of environmental services. Through active management of these trade-offs, livelihoods and food security can be improved. Farm households pursue multiple

objectives through farming including food security, secured access to land resources, crop productivity and system profitability. In turn, society may be concerned with maintaining environmental goods and services such as carbon sequestration and biodiversity conservation. With appropriate technologies and institutions, these can be managed in concert while improving food security.

These trade-offs may be particularly acute in the tree crop farming system, which most often develops from the conversion of natural rainforests. The extent of modification of the forest environment during the establishment and management of tree crop plantations, and the resulting provision of ecosystem services, vary greatly between systems ranging from tree crop monocultures to single shade tree systems and to complex agroforests. There are also cases of agroforestry management practices in forest / savannah transitional agroecological zones where perennial tree crop systems lead to increased tree cover and enhanced ecosystem services (Jagoret et al. 2011). The overall productivity and income of a tree polyculture system is often higher than monocultures. Multi-component agroforest systems also tend to display higher performance in terms of sustainability, food security and socioeconomic flexibility. Pathways to food security through sustainable and resilient intensification, and trade-offs between outcomes, are discussed further in Chapter 18.

Note

- 1 The land equivalent ratio measures how much more total production is increased by combining enterprises on the same piece of land versus managing them separately.

References

- Alliance for Green Revolution in Africa (AGRA). (2016) *Africa Agricultural Status Report 2016: Progress Towards Agricultural Transformation in Africa*. AGRA.
- Amede, T., Auricht, C., Boffa, J.-M., Dixon, J., Mallawaarachchi, T., Rukuni, M. and Tecklewold-Deneke, T. (2017) *A Farming Systems Framework for Investment Planning and Priority Setting in Ethiopia*. ACIAR Technical Report 92, Canberra.
- Ayantunde, A.A., de Leeuw, J., Turner, M.D. and Said, M. (2011) Challenges of assessing the sustainability of (agro) pastoral systems. *Livestock Science* 139: 30–43.
- Dixon, J., Gulliver, A. and Gibbon, D. (2001) *Farming Systems and Poverty. Improving Farmer's Livelihoods in a Changing World*. FAO and World Bank, www.fao.org/farmingsystems/.
- FAO (2017) *Africa Regional Overview of Food Security and Nutrition: The Food Security and Nutrition-Conflict Nexus: Building Resilience for Food Security, Nutrition and Peace*. FAO.
- Faurès, J.M. and Santini, G. (2008) *Water and the Rural Poor: Interventions for Improving Livelihoods in Sub-Saharan Africa*. Water Resources, Development and Management Unit of FAO.
- Fischer, T., Byerlee, D. and Edmeades, G. (2014) *Crop Yields and Global Food Security: Will Yield Increase Continue to Feed the World?* Australian Centre for International Agricultural Research.
- Harris, D. and Orr, A. (2013) Is rainfed agriculture really a pathway from poverty? *Agricultural Systems* 123: 84–96.
- Herforth, A. and Ahmed, S. (2015) The food environment, its effects on dietary consumption, and the potential for measurement within agriculture-nutrition interventions. *Food Security* 7: 505–520.
- HLPE (2017) *Nutrition and Food Systems. A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. FAO.
- Howieson, J.G. and Dilworth, M.J. (eds) (2016) *Working with Rhizobia*. Australian Centre for International Agricultural Research.

- IFAD (2010) *Rural Poverty Report 2011. New Realities, New Challenges: New Opportunities for Tomorrow's Generation*. IFAD.
- Jagoret, P., Michel-Dounias, I., Snoeck, D., Todem Ngnogu, H. and Malzieux, E. (2011) Afforestation of savannah with cocoa agroforestry systems: a small-farmer innovation in central Cameroon. *Agroforestry Systems* 86(3): 493–504.
- Karanja, N., Njenga, M., Gathuru, K., Karanja, A. and Munyao, P.M. (2010) ‘Crop–livestock–waste interactions in Nakuru’s urban agriculture’, in G. Prain, N.K. Karanja and D. Lee-Smith (eds) *African Urban Harvest: Agriculture in the Cities of Cameroon, Kenya and Uganda*, Springer and IDRC.
- Langeveld, H., Dixon, J. and van Keulen, H. (eds) (2013) *Biofuel Cropping Systems: Carbon, Land and Food*. Routledge.
- Lee-Smith, D. (2010) Cities feeding people: an update on urban agriculture in equatorial Africa. *Environment and Urbanization* 22(2): 483–499.
- Lilja, N., Dixon, J. and Eade, D. (eds) (2010) *Participatory Research and Gender Analysis: New Approaches*. Routledge.
- MEA (Millennium Ecosystem Assessment) (2005) *Ecosystems and Human Well-Being: Health Synthesis*. World Resources Institute.
- Rosling, H. with Rosling, O. and Rosling-Ronnlund, A. (2018) *Factfulness*. Sceptre, Hodder and Stoughton.
- van Ittersum, M.K., Martin K. van Ittersum, van Bussel L.G.J., Wolf, J., Grassini, P., van Wart, J., Guilpart, N., Claessens, L., de Groot, H., Wiebe, K., Mason-D’Croz, D., Yang, H., Boogaard, H., van Oort, P.A.J., van Loon, M.P., Saito, K., Adimo, O., Adjei-Nsiah, S., Agali, A., Bala, A., Chikowo, R., Kaizzi, K., Kouressy, M., Makoi, J.H.J.R., Ouattara, K., Tesfaye, K. and Cassman, K.G. (2016) Can sub-Saharan Africa feed itself? *PNAS* 113(52): 14964–14969.
- van Velthuisen, H., Fischer, G. and Hizsnyik, E. (2013) *Technical Annex: FS Characterization with GAEZ Data*. The African Farming Systems Update Project. IIASA.
- World Bank (2009) *Awakening Africa’s Sleeping Giant: Prospects for Commercial Agriculture in the Guinea Savannah Zone and Beyond*. World Bank.

18 Ways forward

Strategies for effective science, investments and policies for African farming and food systems

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Key messages

- The African farming system framework should be used to guide regional and national policy makers, science leaders and agricultural investment plans, as well as development partners.
- Farming systems vary in the institutional, technological, market and social capital requirements to improve household food and nutrition security, and national and regional food systems.
- Development of future food and nutrition security strategies should be based on farming systems analyses and deploy decentralized systems and participatory methods to ensure consistency with farming system needs.
- The core elements of an effective food and nutrition security strategy are:
 - policy and institutional environments which mainstream farming systems and create appropriate incentives for farmers and agribusiness to implement sustainable intensification and diversification in the context of rural transformation
 - access to markets, information and other agricultural services as these play a very important role in reducing productivity gaps, and improving household food and nutrition security. Therefore, support for agricultural service providers and value chains should be a priority investment, suitably targeted by farming system
 - increased investment in innovation systems and research, incorporating trans-disciplinary systems analysis with a particular focus on reducing productivity gaps and boosting novel on-farm diversification
 - inclusive development that strengthens human and social capital in suitable ways for each farming system, and makes full use of digital options
 - access to productive resources, which will require restoring degraded land, sustainable use of the extensive groundwater reserves, and functional usufruct rights to cultivated land and common grazing lands
 - sustainable and resilient intensification and diversification with suitable climate-smart practices to improve food and nutrition security in all farming systems despite climatic variability and market volatility.

Summary

This chapter draws on the farming systems analysis in previous chapters to outline key elements for regional or national food security strategies – as one of the multiple goals of policy makers. The farming systems framework encompasses the characteristics, drivers, pathways and strategic interventions for the 15 farming systems and more than 50 subsystems in Africa. The framework is an exceptionally valuable knowledge base for policy makers and science leaders and has been incorporated in the Science Agenda of the Forum of Agricultural Research in Africa and has provided basic knowledge for the National Agricultural Investment Plans.

By considering the seven principal drivers and trends for each of the farming systems, the framework informs understanding of the development pathways for each system. The strategies preferred by households inform policy makers of the likely responses to new policies, infrastructure or markets. The household strategies differ significantly between the extremely poor (reduction of poverty) and the less poor (income generation). The relative emphasis of households on on-farm intensification, diversification, off-farm income or exit from agriculture depends on the farming system and its food security potential.

Transformational adaptation strategies should be sought for sustaining household food security, income and resilience, based on similar categories of farming systems. Successful intensification of staple enterprises will enable diversification to high value crops, trees, livestock and fish. Strengthening resilience will be especially important in the riskier low and medium potential farming systems, where transition to climate-smart agriculture would pay dividends. Two resource management thrusts are important, namely, sustainable management of the land in all farming systems and the sustainable use of the massive groundwater reserves, especially in the low and medium potential farming systems. A high priority is the development of technological and institutional innovations which will enable the massive gaps between actual and potential productivities to be reduced.

Inclusive development will require strengthening of human and social capital in all farming systems, with particular reference to the empowerment of women and the extremely poor, and the coordination of public and private sectors and community initiatives. Local access to agricultural advisory services, especially markets, will be enabled by local infrastructure and digital information services. Boosting support for agricultural service providers and value chains should be a priority investment and will contribute to reducing the large yield gaps and improving food and nutrition security. The reform of institutions to remove biases against smallholders and women farmers can also create incentives for households to implement sustainable and resilient intensification and diversification, which has the added advantage of providing a buffer against climatic and market variability. Appropriate incentives will also foster rapid scaling-out of sustainable and productive innovations, which will strengthen food systems and improve food and nutrition security.

Introduction

This chapter draws on the African farming systems analyses of Chapters 3–16, consolidated in Chapter 17, to inform policy makers, scientists and development partners of the key options for boosting smallholder and national food security. While Chapter 17 outlined the potentials for improved food security, based on the farming systems analyses, this

chapter discusses the implications for scientific and policy-based food security strategies. The first section summarizes the farming systems framework, considers the roles of the drivers of change in a foresight perspective and discusses some applications of the framework. Within the context of trends in African agriculture, the second section outlines key elements of strategies for food security. The final section considers aspects of stakeholder engagement and implementation.

The farming systems framework

Structure and contents

The farming systems framework and analyses presented in this book constitute an evidence base for refining and implementing the decisions by policy makers and science leaders needed to tackle the immense challenges and opportunities for African agriculture up to the year 2030 and beyond. The broad challenges include a deteriorating resource base leading to inadequate food, nutrition and income security and equity for the African population, while the general opportunities include increasing productivity in sustainable ways and stimulating national and regional food systems, trade and economic growth (AGRA 2017). The directions for development have been set forth in the 2014 Malabo Declaration that aims, primarily, to eradicate hunger in Africa by 2025 within the context of a fully transformed agriculture.

The importance of understanding farm households and farming systems was recognized by African leaders in the resolutions of the Malabo Declaration, for instance, to ensure that by 2025 at least 30 per cent of all farm, pastoral and fisher households are more resilient to climate- and weather-related risks. Understanding of farm households is required to develop the resilience-building initiatives (including social security for rural workers and other vulnerable social groups) and mainstreaming resilience and risk management in policies, strategies and investment plans.

Without a doubt, smallholder family farms will continue to dominate most African farming systems up to 2030 and beyond (AGRA 2017). Smallholders make decisions on their farms about agricultural resource management, production and marketing which influence agricultural sector growth, sustainability and resilience – within the prevailing context of institutions, agribusiness, infrastructure and policies.

The farming system framework identifies 15 broad farming system zones in Africa (hereafter referred to simply as farming systems or systems), most of which cut across many African countries (Figure 18.1b). Each farming system is characterized by distinct patterns of access to agricultural resources; access to agricultural services (especially markets); the resulting production, consumption, investment and livelihood patterns; and different constraints and development opportunities. Thus, farmers in different farming systems would benefit from different technologies, investment and policies.

The 15 farming systems are further divided systematically into subsystems, of which 45 are mapped and a further 8 defined and described. There are recognizable patterns of heterogeneity of soils, slopes, market access and household types (including small and large, poor and rich) within any farming system. Among the 15 farming systems, an average farming system has an agricultural population of 41 million people, excluding the urban and peri-urban farming system (ranging from 4 to 107 million, excluding the urban and peri-urban farming system) living on 206 million ha of land, of which 17 million ha

are cultivated, and managing 22 million tropical livestock units (TLU) of mixed livestock. However, the uniqueness of each farming system requires differentiated understanding and separate targeting of development interventions.

Farming systems are dynamic, influenced by changes in their settings. The farming systems analysis in this book applied foresight approaches to document drivers of change, trends and likely future forms of African agriculture. Farming systems are evolving along recognizable pathways, propelled by seven main drivers:

- population growth
- natural resources and climate
- energy
- human knowledge and gender equity
- technology and science
- markets and trade
- institutions and policies.

These seven drivers align with three megatrends and challenges identified by the Agenda for Science in Agriculture in Africa (FARA 2014): Climate, policy and institutions, and improving rural livelihoods. Sometimes, the expected trajectories are punctuated by economic or climatic shocks, depending on the degree of resilience of the farming system.

Farm households have various strategies that influence their decisions to adopt (or discard) technologies, and also their responses to policies that together shape the development pathways for each farming system. In order to improve food security, reduce poverty and increase farm income, farm households choose various mixes of the following five strategies:

- the intensification of existing production patterns and practices
- on-farm diversification with new activities
- farm business growth with more land, livestock or capital
- increasing off-farm income
- making an exit from agriculture to urban employment.

Naturally, the strategy mix differs between farming systems, and also between the extremely poor half of the population and the less-poor households. Sometimes the strategies are implemented in unexpected ways, for example many agropastoralists have begun investing in small-scale irrigation for on-farm diversification; and farm households increase off-farm income by sending their children to school or abroad in order to earn remittances. The chosen combinations of these strategies (for poverty reduction and for income growth) influence the development pathways open to any particular farming system as a whole and the effectiveness of chosen policies.

Learning from recent change

Farming systems are evolving because of population pressure, degrading resources, changing weather patterns, improved technologies, markets, consumer preferences, changing policies and other drivers of change, as discussed earlier. The changes in African farming systems over the period 2000–2015 have been substantial, as shown in Figures 18.1a and b,

which contrasts the Africa farming system map of 2000 (Dixon et al. 2001) and the map of 2015 (this book). For example, central African areas have been reclassified (enlarging the maize mixed farming system) where maize has been widely adopted in areas that were originally cereal-root crop mixed systems. The forest-based farming system in the Congo has shrunk due to loggers' roads opening up the forest for opportunistic settlement. The entire large commercial and smallholder farming system has been reclassified to maize mixed, agropastoral and, notably, a new farming system called perennial mixed, which embraces the mixed food and perennials production found in coastal southern Africa as well as a rainfed perennial crop-livestock subsystem in north Africa.

Because market opportunities expanded and stimulated increased diversification in some areas, parts of the maize mixed system have been reclassified into the commercial smallholder highland perennial system. Boundaries of many systems have been adjusted, reflecting increased population density, improved infrastructure and access to agricultural services, and improved technology and institutions.

Figure 18.1a Farming systems of Africa, 2000.

Note: The 2000 map is a composite of SSA and north Africa maps in Dixon et al. (2001).

Figure 18.1b Farming systems of Africa, 2015.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.

Note: Because of lack of comparable data, the urban and peri-urban and the island farming systems were not mapped in either 2000 or 2015.

Quite apart from the major spatial changes shown in Figures 18.1a and b, the seven drivers of change are also causing incremental adjustments to system structure and composition, many of which were anticipated in Dixon et al. (2001). Some changes are visible in terms of new livelihood patterns, for example, adoption of pigeon pea, small-scale irrigation or tree establishment in food crop fields in the maize mixed system. Some other changes are largely invisible, for example, declining soil fertility in the perennial mixed system, and the strengthening of social capital with farmer-managed natural regeneration in the Sahelian agropastoral system. The combination of modified rural consumer preferences, increasing conflicts between pastoral groups (which is limiting movement) and the availability of a range of stress- (or drought-) tolerant maize, has stimulated expansion of maize, alongside

sorghum and millet, in the agropastoral farming system. Market development has expanded the opportunities for smallholders in east Africa, in particular in horticulture and dairy.

Despite the adjustments to the farming systems classification, it is clear that the framework is robust and enables policy makers to anticipate, and plan for, future changes. In coming decades, trade and market drivers will be influential, as well as technologies and information services. Compared with 2015, smallholders in 2030 will be more connected and more commercialized. The cereal-root crop and maize mixed farming systems will have intensified and diversified, with significant emigration from the latter. Building on the farming systems analyses in Chapters 3–16, foresight studies framed around the seven drivers would add detail to the likely patterns of farming in 2030 and beyond.

Application of the farming systems framework to policy and investment

Although farming, fishing and pastoral households differ, they can be grouped into broadly similar and recognizable types of farming system (or clusters of similar farming systems), which facilitates decisions by policy makers, business leaders and scientists on the design and targeting of strategies, investments and actions to assist different types of farmers.

The farming system framework can add a spatial element to policy formulation and implementation, and it can underpin research priority setting. For example, the effects of input subsidies or social safety nets can be usefully differentiated across farming systems. Those public programmes or policies, which are focused on particular resources, for example irrigation water or particular commodities such as dairy or cassava, can be better targeted to farming systems where the impact will be most needed or be most beneficial.

For research managers, production constraints and the pay-offs to new technologies can be assessed by farming system in order to determine research priorities. Similarly, export programmes can be sharpened by estimates of competitiveness of target commodities in different farming systems. Understanding farming systems commonalities and differences is also useful for businesses when developing a competitive strategy for the marketing of inputs, or the purchase and processing of crop and livestock produce. Thus, the farming systems framework can inform many practical public and private decisions for sustainable rural development.

There is a variety of ways that the farming systems framework can complement national statistics and other analyses for policy makers and science leaders. The FAO/World Bank study (Dixon et al. 2001) influenced the World Bank Rural Development Strategy update in 2001 and subsequent investment (Dixon 2006), and underpinned a development strategy for Africa (InterAcademy Council 2004), an FAO Africa water strategy (Faurès and Santini 2008) and guided the prioritization of a number of CGIAR Research Programs in Phase 1. Thus, it has arguably encouraged the application of farming systems analysis to science and policy strategies. The following three cases illustrate the diverse ways in which the framework is relevant to Africa.

Science agenda for African agricultural development

African leaders recognize that for agriculture to serve as the engine for growth, the sector must be transformed. The Comprehensive Africa Agriculture Development Programme (CAADP), launched in 2003, aims to improve agricultural output by at least 6 per cent per year. To achieve this target, African leaders committed to allocate at least 10 per cent of their national budgets to the agricultural sector, with a focus on sustainable land management and

reliable water control systems, rural infrastructure and trade, food supply and hunger, and agricultural research, technology dissemination, adoption and capacity development.

In this connection, CAADP identified three principal services for improving productivity, notably research, delivery systems (advisory services) and capacity development, and called for these services to place the small-scale farmer at the centre of their missions. However, investment in agricultural research is low – the agricultural research intensity is 0.5 per cent compared with the recommended intensity of around 1 per cent – and the fragmentation of the African agricultural research landscape has undermined its efficiency and the impacts of the research investment of the National Agricultural Research Systems (NARS).

Consequently, the Agenda for Science in Agriculture in Africa (S3A) was formulated, focused on setting research priorities, to be a primary guide for science and technology planning at all levels (FARA 2014). S3A incorporated the farming systems framework and map, noting that more than 70 per cent of Africa's crop and livestock producers who are poor are found in five farming systems, viz, the maize mixed, agropastoral, highland perennial, root and tuber crop, and cereal-root crop systems. As S3A emphasized, development strategies based on science and technology solutions vary from one system to another and include: intensification, diversification, increased farm/herd size, increased off-farm income and exiting from agriculture. Using transformational system analysis and model predictions, the farming system approach can be used to identify key development barriers and potential scientific solutions for the respective farming systems, while recognizing market demand as an important driver of development to incentivize intensification and diversification.

National (CAADP) investment plans

A core element of CAADP implementation is the preparation of National Agricultural Investment Plans. Recognizing the diversity of African agriculture, the farming systems framework was piloted in Ethiopia – with perhaps the greatest diversity of agricultural environments of all African countries – to provide structured information and analysis, and to identify critical investments required for sustainable intensification of Ethiopian agriculture (Amede et al. 2017).

Using the approach of the African farming systems analysis, new farming systems maps were created specifically for investment planning in Ethiopia (Figure 18.2). The farming systems characterization and information frameworks assembled during this exercise represent a useful planning support tool which complements existing efforts such as national land resources planning.

The national farming system framework offers a strong basis to plan improvements in major farming systems to maximize economic benefit and safeguard the natural environment, by associating key growth targets with areas of greatest potential for sustainable social benefit. The detailed understanding of spatial distribution, trends and patterns of growth in farming systems helps coordinate sector-wide growth plans and targeted interventions such as fertilizer factories and commercialization clusters for accelerating agriculture-led growth.

It can also guide scaling-up and scaling-out strategies and monitoring and evaluation. For instance, the Ethiopian Institute of Agricultural Research (EIAR) is planning to use the farming systems approach for developing specialized research centres and for framing the sharing of responsibilities among the national and regional agricultural research and teaching institutes. The methodology could be replicated in other countries as long as

Figure 18.2 Ethiopian farming systems, 2015.

Source: Amede et al. (2017).

some basic spatial datasets are available, including land cover, soils, cropping and livestock production, and market access. The approach allows the flexibility to integrate additional geographic data with other disciplinary knowledge to refine classifications, pathways and investment requirements. Such advances in information management and planning will help to minimize externalities and enhance sustainable agricultural intensification, which contributes to national economic growth.

Priority commodity policies and programmes

Regional and national policy makers often prioritize particular agricultural commodities for development programmes. However, in Africa commodities are rarely grown as sole monocultures, therefore the farming system context is of critical importance in designing effective programmes for priority commodities. Table 18.1 illustrates the location of major areas of five commodities (maize, sorghum, wheat, cassava and groundnut) by farming system.

For example, the best adapted areas for wheat are in the highland mixed farming system, with poor market access and major livestock herds, and in the perennial mixed systems,

Table 18.1 Distribution of selected adapted crops by farming systems

Farming system	Maize	Sorghum	Wheat	Cassava	Groundnut
Maize mixed					
Agropastoral					
Highland perennial					
Root and tuber crop					
Cereal-root crop mixed					
Highland mixed					
Pastoral					
Perennial mixed					

Source: Adapted from van Velthuis et al. (2013), where each block above represents greater than 10 per cent of the land under the particular crop. However, these crops can also be major components of other farming systems, for example maize in fish-based and irrigated systems, and cassava in the forest-based system.

where export cash crops of fruit, grapes and olives would compete for inputs and farmers' attention. Cassava is not only found in the root and tuber crop farming system, but significant areas are also grown in the cereal-root crop system, integrated with sorghum and millet, and the maize mixed systems, alongside maize, sorghum and many other crops. Farming system data such as yield or proximity of markets help to indicate where commodity programmes could be targeted, and also the different 'systems' contexts in each location.

The farming systems analyses in Chapters 3–16 also illustrate the importance of interactions between commodities in each farming system. The nature of the interactions has important implications for the design of commodity programmes. For example, cereals and legumes can compete for land in low rainfall environments with short growing seasons (for example in the agropastoral system), but be synergistic in longer growing seasons such as the highland perennial system where intercropping and multiple cropping is possible. Where commodities are competitive, an awareness of opportunity costs of expanding the commodity is needed; where commodities are complementary, commodity programmes could linked or merged. One aspect of complementarity of enterprises is the way in which the intensification of main crop and livestock enterprises (including, but not limited to, staples) often encourages on-farm diversification to higher value commodities. The intensification of food crops releases land and labour resources for the new enterprises, and the risk of new products can be shared across multiple enterprises in the farm household system.

Elements of a regional food security and food system strategy grounded in knowledge of farming systems

Farming systems analysis helped identify the strategic interventions for each farming system outlined in Chapters 3–16. As explained in Chapter 1, smallholders are both producers and consumers, so increased performance of the farming system contributes to improved household food security through both increased food production (for home consumption) and purchase entitlements. Bearing in mind that Africa's farm population approaches half of the total population, both production and consumption aspects of food systems need to be strengthened.

The knowledge of farming systems can also contribute to improved food security and food system strategies, as illustrated in this section. First, the needs of different farming systems can be identified (consider the contrast between root and tuber cropping and pastoral livelihoods and their respective food security needs). Second, knowledge of the responsiveness of farm households to opportunities from new market, technology or policy opportunities (which varies between the farming systems, and between categories of households with a farming system) contributes to the design of the strategies.

The collective effect of decisions across a population of farming system households with similar characteristics will shape the responses to changes in their farming environment, including adjustments in policies, infrastructure, market access, technologies and information – and consequently, the evolution of farming systems along predictable pathways, whether semi-subsistence systems or specialized market-oriented systems. Therefore, understanding household strategies for escaping poverty or increasing income, can help devise appropriate development interventions according to farming systems types. Table 18.2 illustrates the most common household strategies for the extremely poor and the less-poor for the low, medium and high food security potential categories of farming systems.

All five poverty escape strategies are important for some extremely poor farm households. In the high food security potential category (Table 18.2), intensification and on-farm diversification are prominent, presumably because of opportunities associated with resource endowment and market access, even for poor smallholders. Households in the medium potential category prefer strategies for intensification and exit from agriculture. Perhaps not surprisingly, poor households in the low potential category prioritized off-farm

Table 18.2 Common farm household strategies for the poor and less-poor in low, medium and high food security potential groups of farming systems

<i>Farm household type (bold) and food security potentials of farming systems</i>	<i>Intensification</i>	<i>Diversification</i>	<i>Farm or herd growth</i>	<i>Off-farm income</i>	<i>Exit from agriculture</i>
Extremely poor					
High potential					
Medium potential					
Low potential					
Less poor					
High potential					
Medium potential					
Low potential					
Total agricultural population					
High potential					
Medium potential					
Low potential					

Source: Based on chapter authors' estimates for individual farming systems.

Notes: Highlighted strategies are estimated to contribute at least 20 per cent to the farmer goals of reduced poverty (for extremely poor) and income generation (for the less poor), or combined for the total agricultural population in the lower portion of the table.

income and exit strategies. As might be expected, the less-poor households favoured intensification and on-farm diversification strategies for all potentials categories; however, the less-poor in high potential areas perceived opportunities for farm and herd growth, and in the medium potential category for off-farm income. Noting that the extremely poor and less-poor each represent about half of Africa's agricultural population, an overall blended strategy mix is suggested by Table 18.2. This information can assist policy makers with adjustment of the portfolio of policies to stimulate improved food security.

Clearly, farming systems are highly dynamic and change over time in response to a number of recognizable drivers. In practice the seven principal drivers of change interact, and the reader might anticipate a fundamental nexus between population density, access to natural resources and access to services including markets, at least for some farming systems such as the highland perennial system with high population density, good access to agricultural services and a history of declining soil fertility.

Drawing on the outline of potential enhancements of food security identified in Chapter 17, Table 18.3 introduces regional strategies to deliver the potential improvements in food and nutrition security through the improvement of farming systems structure and function in Africa; these are discussed in greater depth in the following sub-sections. In Table 18.3, the seven 'thrusts' correspond to the seven areas of the drivers of change, and the 'elements' are the key strategic interventions of the food and nutrition security strategies which relate to farming systems. Each country or region could choose different portfolios of thrusts and elements, depending on local farming and food systems issues, potentials and policy contexts.

Table 18.3 Farming system elements of national and regional strategies for food and nutrition security

Refocus policies and institutions for food security and food systems, including:

- integrate area-based interventions for farming systems development and rural transformation, to underpin Malabo Declaration goals and support sustainable and resilient farming systems intensification and diversification
- promote systems approaches and the farming systems framework to update food security strategies for Africa, especially those by regional and subregional bodies (for example, ASARECA, COMESA, CCARDESA, FARA) and national leaders; and initiate farming system platforms to support and synthesize data collection, analysis, modelling and foresight
- harmonize agriculture-related policies and institutions to remove biases against farm women and poor smallholders, to create safety nets, and to provide coherent incentives for sustainable intensification and diversification
- arrange equitable and transferable agricultural resource users' rights, especially for land and water
- foster innovation and learning systems, especially in markets, finance and risk sharing to overcome institutional failures.

Strengthen trade and markets for food security and food systems, including:

- focus on entrepreneurial startups with opportunities for youth, for example in agroforestry nurseries, mechanization and niche product value-adding
 - facilitate regional food trade with linkages to specific high potential farming systems
 - blend public and private investments for local roads, markets and financial systems to reduce capital and transaction costs, especially in low and medium potential farming systems
 - support specific value chains, selected for each farming system, which encourage sustainable diversification
 - regulate for safe and labelled food, especially for domestic and regional markets in the cereal-root crop mixed, highland perennial and other high potential systems.
-

(continued)

Table 18.3 (continued)

Deploy science and technology for food security and food systems, including:

- double national investment in agricultural research to reach 1 per cent intensity
- organize farmer and business engagement in priority setting and project cost sharing, organized by farming system
- build capacity for systems-adaptive research, integrating biophysical and socioeconomic investigation to develop effective technological and institutional innovations for complex farming and food systems challenges
- complement innovations for intensification with research on sustainability (soils, water, trees, carbon), resilience (climate-smart insurance) and diversification (fish, dairy, horticulture)
- develop appropriate mechanized, precision, sensor and automated solutions with ICT-enabled decision support tools.

Build human and social capital, knowledge sharing and gender equity for food security and food systems, including:

- strengthen social capital as a game changer for rural transformation, including innovation platforms which bring multiple stakeholders together for local learning and scaling-out
- incentivize lifelong capacity enhancement for farm households and agricultural service providers
- empower women for successful roles in farming, local business and as community leaders
- create centres of learning on systems research applicable to development
- invest in ICT-based ‘big open data’ systems and remote sensing for knowledge sharing and decision support directly to farmers and businesses.

Boost rural energy availability for food security and food systems, including:

- encourage small and large tractor and combine harvester use, and support equipment such as no-till drills and small power units (both fossil fuel and increasingly, electric) to boost returns to farm labour and reduce women’s workload
- invest in rural electrification, especially through community-managed renewable energy systems (solar, biomass, microhydro, wind) with storage
- promote efficient stoves leading to reduced wood fuel use and improved health
- foster energy-efficient transportation, farm input use, processing and storage of food and agricultural products
- take advantage of the comparative advantage of the medium and high potential farming systems for biomass and biofuel production.

Sustainably manage natural resources and adapt to climate within food security and food systems, including:

- emphasize sustainable resource management and production (and consumption) to underpin sustainable and resilient farming systems intensification in all systems
- shift orientation of increased food production from land expansion to yield intensification, using information and incentives, especially in medium and high potential systems
- foster integrated approaches to resource management and restoration and to increase the proportion of perennials in all farming systems
- manage groundwater reserves intelligently and cautiously, especially in the agropastoral and pastoral systems, to avoid the depletion experienced in other continents
- focus on climate-smart agriculture and adaptation to climate variability, including weather index-based crop and livestock insurance for the riskier agropastoral and pastoral systems.

Respond to population and poverty pressures for food security and food systems, including:

- ensure availability in rural areas of quality schooling, especially for farm girls
 - incorporate farm production, consumption, nutrition and health topics into curricula of schools and farmer training facilities
 - foster safe and effective movement of farm and pastoral people between systems and from farms to towns and cities
 - create jobs for youth in the entire agrifood system, from farming to town employment schemes in agrifood chains and retailing (training, credit, groups), especially in low potential farming systems with high levels of exit from agriculture
 - focus on rural employment creation based on labour-efficient institutions and labour-saving technologies.
-

As noted earlier, policy makers, investors and researchers will need to select the mix of thrusts and elements that are relevant to their regional or national contexts, or to any particular target farming systems. The selection of suitable development interventions requires a deep understanding of the interactions between the structure and function of the farming and food systems and the implications for food and nutrition security at household, national and regional levels. The elements of Table 18.3 relate to the national and regional levels, and contrast to the interventions identified in Chapters 3–16 for specific farming systems, such as the following list of example interventions: rainwater harvesting; improved production practices for major food crops, livestock and tree crops; improved production practices for minor cereals, root crops and pulses; better crop-livestock integration; improved crop storage and processing; improved market institutions and road access; farm household risk management; building women's knowledge, skills and capacity in farming systems; systems analysis and scenario modelling; and fundamental investment in building capacity and extension delivery that is grounded in a solid understanding of resource management, farming systems and the social and institutional contexts.

Institutions and policies

Positive developments have taken place in Africa in the liberalization of trade and markets, the strengthening of institutions (used in the sense of the 'rules of the game' that influence farmer, business and public agency decisions) and public policies, the sharing of information and knowledge, and in investments in social capital. Despite this, common constraints in most farming systems include land tenure insecurity, poor road infrastructure, limited access to markets, competition from cheap imports, inadequate agricultural research and extension capacity, and lack of education for youth to seek off-farm employment. With rapidly increasing populations, governments have struggled to expand the availability of schooling, health care and other infrastructure. This affects labour availability, capacity and skills, and markets.

Farming systems are embedded in rural landscapes and economies with strong interlinkages. In keeping with the Malabo Declaration, emphasis should be sustained on broad-based transformative approaches to the rural sector. Arguably, one of the core constraints to food security and rural transformation is institutional failure. In many countries the prevailing institutions are biased against women smallholders, and smallholders in general – and in many respects against rural businesses which are essential for connectivity of farms to local and domestic markets. The way that institutions generate incentives and relationships should be examined, to embed and create equitability in policy formulation and application.

The application of this farming system framework by national policy makers and planners and regional agencies (for example, Forum for Agricultural Research in Africa (FARA), Sub-Regional Organisations (SROs), New Partnership for Africa's Development (NEPAD) and the Africa Union itself) would provide the evidence increasingly sought for agricultural and rural development. There would be great value in establishing farming system platforms with the capacity for farming systems data collection, analysis, modelling and foresight, for sharing within Africa.

Within a rural transformation agenda, the role of the farm economy in creating strong multiplier effects in the non-farm economy needs to be better understood. Transferable and equitable land and water rights are important to create the proper incentives and efficient allocation of resources. This is also a 'work in progress' in most other regions of the world.

The integration of three sets of food security policies are important in this context: supply-side, value chain/market and demand side (Qureshi et al. 2015). Such a structured approach helps to identify and remove conflicts between policies, within and between sectors. In the process, a systematic assessment of effectiveness and equitability of subsidies should be encouraged, with a view to removing biases, especially against smallholders and women.

In commercializing farming systems with small farm size constraints, it is essential to reduce the transaction costs in land markets. Tenure security is important, especially for vulnerable groups (pastoralists, women, migrants), along with control and better management of grazing lands and improved communal water management. There are also promising outcomes from management of lands by rural cooperatives and collective clustering arrangements in Ethiopia. The access to productive inputs is critical, for which policies are required to promote access to credit, insurance and inputs, to boost production and to reduce deforestation and the need for additional land.

Input subsidies have been popular in some countries but have not been fiscally sustainable, so exit strategies are needed (Jayne et al. 2018). The Common Market for Eastern and Southern Africa (COMESA) has created an EverGreen Fertilizer Subsidies Platform to assist countries to refocus their subsidies towards integrated soil fertility solutions with fertilizer shrubs and trees. This is a highly commendable approach to creating more sustainable value-added to smallholder farmers through subsidy programmes.

Functioning markets are central to intensification and diversification – through publicly funded storage and transportation infrastructure, market information programmes and the reduction of entry barriers to new agents. The real issue for farming systems is the ‘last mile’ in access, often enabled by local roads (Box 18.1), market sheds and yards – especially given the widespread availability of market information on mobile networks.

Growth in productivity depends on adequate production incentives, for which low input prices and high and reliable produce prices are fundamental. Efficient input and produce markets create permanent incentives leading to investments in a way that does not occur with short-term subsidies. Since the majority of farming systems now produce at least some food surpluses in good years, the balance between producer incentives and consumer prices is a policy challenge – particularly with the cheap imports of cereals (rice, wheat) in many countries that are displacing the supply of locally grown cereals and starchy staples (cassava, yams, cocoyams, plantains). One potential policy intervention is mandatory inclusion of local crops in composite food products (e.g. 10 per cent cassava flour in bread products in Nigeria) to promote the use of this local root crop.

Perhaps the most enduring investments are policies that strengthen the national research capacity, especially for farming systems with high potential for growth, and support private sector engagement through tax incentives for industrial utilization of crops (e.g. roots, tubers, sorghum) as raw materials for food and other purposes. Because domestic and regional markets will be a major opportunity for smallholders in the coming decades, a critical priority is to further reduce the barriers to cross-border agricultural trade. This process is already underway through new momentum towards free trade agreements.

Clearly, urban and peri-urban systems will continue to grow in the short term, and so public support for land and water access, markets and food safety are important. There are many opportunities for improved nutrient cycling through better waste management which could, at least partially, cost-effectively substitute for expensive fertilizer imports.

Box 18.1 Engines of agricultural development in Africa: maize mixed and cereal-root crop mixed farming systems

In 2015, these two farming systems had a combined agricultural population of 150 million, a cultivated land area of 74 million ha and a livestock population of 65 million TLU. Both systems are located in subhumid plateaux areas with a medium growing season length of 180–200 days. Area expansion has been a major source of previous growth in food production in these systems. However, this is now slowing down, with the frontier of agricultural land pushing into the remaining forests. Pockets of diversification and intensification demonstrate the technical feasibility and economic benefits of fertilizer application to food crops, the development of important agroforestry systems, and the production of forages for livestock and dairy development. Nevertheless, off-farm work is a significant contributor to income in most households, which generates new ideas that migrant workers bring back to their communities to stimulate change. The development of road networks in the past few decades has given most of the rural population in these systems a moderate or good access to input and produce markets. These systems have the potential to be a food basket and a driver of agricultural growth and food security in the region.

Markets and trade

Market access is a common problem across most farming systems, and farmer access to input, output and credit markets is still highly constrained. Farmers will not invest in their farm or produce a surplus unless there are markets and attractive prices. Many farmers have to travel more than seven hours to the nearest town of more than 20,000 people, in particular in the forest-based, highland mixed, root and tuber, maize mixed and pastoral farming systems. Because of the rapid rate of urbanization, the greatest growth potential in markets is in domestic and regional markets. Currently, transactions costs are much too high. Improved road networks, supply chain logistics, market institutions and value chains (targeting relationships and value-added of products) could help farmers participate much more actively in trade (see also AGRA 2017). But there is evidence that the situation is improving in some areas.

Clearly, markets will strengthen, and domestic and regional trade will expand, with an increasing involvement of business in the formulation and implementation of market and trade arrangements. Nevertheless, public agencies have a key role to play in providing the enabling environment for efficient market function, especially in relation to regional trade. This calls for negotiations under the continental free trade areas or tripartite free trade experiments in the EAC-COMESA-SADC bloc.

In many cases the traditional cross-border grain and livestock market flows can be improved in various ways – simplifying border handling, agreement on common grading, safety and quarantine requirements. In order to achieve the full benefits of regional trade,

the backward and forward linkages between the involved value chains and the supplying or purchasing farming systems must be functional and efficient. Further, it will be necessary to retool public agencies, including banking and extension, to support farm businesses and market chain activities.

The marketing functions should cover both inputs and produce for intensification and diversification, and labour markets for increased off-farm income. Critically, diversification to new activities generally requires new value chains (Box 18.2), or at least new functions and commodity streams. In fact, better access to a wider range of market services is a critical requirement for the intensification and diversification of all systems. Irrigated systems are in a good position to respond, as are the highland perennial and perennial mixed systems.

The strategic challenge is to provide these opportunities to the systems with high and medium potential for growth, notably the cereal-root crop and the maize mixed systems (Box 18.1). As noted in the previous section, support for transport and storage infrastructure would be a priority investment. Improving market information will have even wider and faster impact for many farming systems. M-PESA has already opened up remarkable opportunities for Kenyan smallholders in remote areas; other ICT-based tools will improve market functioning, financing and arbitrage. The private sector will increasingly shape the opportunities for farming systems over the coming decades, both directly and indirectly. Such influences can already be seen quite clearly in the horticultural industries.

Many systems would benefit from policies that decentralize processing and manufacturing to rural areas to create rural employment and off-farm income (as was implemented on a wide scale in China). In a related fashion, for remote areas such as the forest-based system, policies to support transport and economic corridors and cluster development would stimulate production and markets, for example farm and community development around mines.

Box 18.2 Micro- and small enterprises

Beneath every successful international value chain lies local medium-sized and micro-enterprises, which require nurturing and development (AGRA 2017). Local training and business services suitable for micro-enterprise start-ups are rarely available, but are a priority need. Careful support can reduce the notoriously high failure rate of start-ups. Given the projected growth of markets and the emerging communication technologies, the widespread establishment of agricultural micro- and small enterprises could stimulate an agricultural revolution, with substantial employment and income dividends.

Input markets are often a lever for change, such as the smallholder-linked seed systems for legumes and ‘minor’ crops. Diversification into higher value agricultural products is a high priority for many systems. It requires the development of a wider range of input services, including seed, chemicals, finance, insurance and market information. This is especially true for those systems which are positioned to capture niche markets, for example

tourism, medicinal products, highland fruits, flowers, honey and other organics from the highland mixed farming system.

Technology and science

The range of technologies and institutional innovations available to small farmers has steadily increased in Africa, even as public research capacity has declined in many countries. African farming systems could be on the cusp of massive technology-driven and market-enabled transformation; there are some signs that it is already occurring in the pockets of successful intensification. Africa will also benefit from the spillovers of research products from advanced regions including the OECD and Asia. Many emerging branches of science will reshape agricultural technologies, including ICTs, biotechnologies and precision agriculture.

Technology, along with functioning institutions and agricultural services, will be a driver of farming systems development. A first priority would be to increase funding for agricultural research – ideally to double the amount of funding. Improved varieties and production practices have assisted in some systems (e.g. crops in highland perennial, water management in large-scale irrigation and livestock disease management in the pastoral systems), but in most systems the fit of the technology into the whole farm household system is often poor, for example interdependent crop and livestock enterprises, or farmers being limited by poor access to inputs and extension services. Across a range of farming systems, better access to improved crop varieties, livestock breeds, and modern inputs and better integration of farm enterprises, which can be incorporated seamlessly into existing systems, could deliver substantively increased production. Farming systems adaptive research, along with improved farm management, is an extremely high priority to reduce the massive yield gaps in most farming systems (Fischer and Connor 2018). The initial target could be the high potential farming systems where crop yield gaps in the order of 75 per cent of potential yields are not uncommon (van Ittersum et al. 2016; van Velthuis et al. 2013). There are many relevant research areas which complement innovations for resource management, improved germplasm and production practices. For example, there are massive opportunities for innovations, customized to fit into existing farming systems, in relation to appropriate mechanized equipment, precision agriculture, ICT-enabled sensor and decision support tools which would support farm and herd management, increase efficiency and returns to labour, and expand food production in medium and high potential farming systems such as the maize mixed and cereal-root crop mixed systems.

Many of the issues that were identified in Chapters 3–16 would benefit from new technologies. The following examples relate specifically to technological innovations, in contrast to the example list of strategic interventions for farming systems presented earlier. The examples where new technologies are required include: integrated soil fertility management to address soil fertility problems; use of improved grain and multiple purpose legumes for biological nitrogen fixation, in rotation, or as intercropped with cereals; integration of fertilizer shrubs and trees; composting of plant available material; integrating more trees into the farming system for increased income and to enhance fuelwood production to reduce the use of dung and crop residues for fuel; balanced, blended and micro-dosing fertilizer application; improved fallows with leguminous trees; labour-reducing technologies; conservation agriculture based sustainable intensification; cereal-legume mixed cropping systems; root and tuber crop production practices; establishing trees in croplands

in ways that optimize their productivity interactions and minimize their competition for nutrients and water; processing technology for new millet, sorghum and cassava products that generate income from surplus production and avoid the price collapses that tend to occur in favourable years.

Innovations in technology are complemented by innovations in institutions, such as learning institutions (for example, farmer-to-farmer learning), market access (for instance, farmer groups for marketing grain and livestock) and common property resource management (such as grazing and water point management committees).

Looking to the 2020s, an innovation systems approach with functional links to users (farm households and agribusinesses) should underpin research. In line with the recommendations of CAADP, the FARA Science Agenda and best practice for rural development, it is essential to increase, ideally double, the investment in agricultural research, to reach 1 per cent intensity, with systematic farmer and business engagement in priority setting and project cost-sharing, organized by farming systems. Second, it is essential to expand the capacity and strengthen the processes for the integration of biophysical and socioeconomic issues in research, in order to develop more effective innovations for crop-livestock, agroforestry, agroprocessing and carbon accumulation systems. In the process, it is important to complement intensification research with more research on sustainability (soils, water, carbon, social capital, and returns to resources and inputs), resilience (risk management, insurance and climate smart practices) and diversification (to integrate fish, dairy and horticulture into mixed farming systems).

The strengthening of systems thinking and enhanced systems research and education are areas of great need and attention. This will effectively bring together biophysical scientists and social scientists in a common enterprise. The lack of education and capacity in integrated systems research and development is a fundamental weakness for most African countries. Such approaches are needed to tackle the increasing number of 'wicked' (complex and uncertain) problems in agricultural development, of which one of the most pressing is how to attain soil, water and social sustainability. Systems skills also contribute to the science of scaling up and particularly to broadening production research.

The second major challenge is to effectively involve the private sector, as is occurring in OECD countries. Systems thinking will contribute to social capital effectiveness. And it will underpin the innovation platforms that enable successful public-private partnerships, which are fundamental to successful scaling out, starting from the local level.

Human and social capital

The educational level of rural people has recently increased substantially in many African countries. Communications technology has also brought much more information and knowledge to small farm households. However, social constraints and lack of education still greatly limit the options for pathways out of poverty. These options include: accessing extension and new technologies, identifying off-farm employment opportunities, and improving the knowledge and capacity of women in agriculture. This is particularly relevant with the feminization of agriculture, as men increasingly work off-farm.

Opportunities for rural women are growing, with improved social inclusivity, widespread schooling and increased university attendance. In this sense, a revolution is in the making. Farm women are increasingly launching small businesses and taking up rural leadership positions. Arguably, the changes could occur most rapidly in systems

with dense populations and good access to services, for example the urban and peri-urban system and the highland perennial system. Such empowerment will be facilitated by modern communications technologies.

In line with the elements of the food security strategy in Table 18.3, the required development actions include women's empowerment that launches them into successful roles in farming, local business and as community leaders. Stronger social capital will be a game changer for rural transformation, and the benefits are already apparent in the innovation platforms (Box 18.3) which are being piloted in many systems to bring multiple stakeholders together for local learning and scaling-out. Unquestionably, a shift from childhood and once-off education to lifelong capacity enhancement for farmers and micro-entrepreneurs, including agricultural service providers will contribute to rural transformation. Also, ICT-based knowledge-sharing systems will better inform farmers and businesses of market conditions, new technologies and regulations.

Farmer and agribusiness capacities will improve in the normal course. The essential challenge for public agencies will be social inclusivity, especially for the extremely poor and for women. The remote farming systems stand to gain more from social inclusivity policies. One approach would be to target training and information dissemination to small-scale farmers, to enable both intensification and diversification. Selective training that includes girls can address gender gaps and improve women's productivity.

Technology also plays a role. Labour-saving technologies to reduce women's domestic burdens are well understood, but many agricultural technologies also influence the gender distribution of labour. Mechanization or no-tillage technologies that replace hoe farming in the maize mixed system can reduce or eliminate women's input to land preparation. Conversely, cut-and-carry stall-feeding practices often increase the work of women and children.

Training need not be confined to agricultural production. The inclusion of entrepreneurship skills, product processing or seed production enables economic diversification and small enterprise development (Box 18.2). There does need to be increased investment in rural education facilities, farmer training centres, and the provision of mobile and distance learning opportunities for remote farmers and pastoralists, particularly in the agropastoral and pastoral systems.

Box 18.3 Innovation platforms

Innovation platforms are a form of institutionalized multi-stakeholder consultation to strengthen social and institutional capitals. This has been successfully trialled in many African farming systems. Local cooperation and knowledge sharing between farmers, extension agents, local government, business and researchers can be enhanced by these innovation platforms (Dror et al. 2016; Makini et al. 2013). The strengthening of local institutions enables better responses to national policy instruments, reducing the prevalence of policy failure. Although so far they have often been established in a research context, their ultimate value will lie in accelerating multi-sectoral sustainable intensification and development.

Energy

Perhaps the scarcest and most limiting resource in Africa is energy. Africa has a far lower energy consumption per capita than any other region. This is especially true in rural areas, and particularly in those farming systems with very poor public services, such as the arid pastoral and oasis system. It is expected that rural energy consumption will increase many fold by 2040. For most rural poor, biomass is the principal source of fuel and often, of light. Access to grid electricity is very limited, although it is slowly increasing. It will remain low for most smallholders for the foreseeable future. Meanwhile, the dominance of fuelwood and charcoal as an energy source drives continuing deforestation, reduces nutrient cycling on the farm and absorbs a great deal of labour non-productivity, especially from women and girls. The fuelwood and charcoal industries cause enormous soil erosion, siltation of dams and widespread respiratory disease (hence the importance of programmes for the promotion of more fuel-efficient stoves), and of course, they also contribute to greenhouse gas emissions. Acute fuelwood shortages affect the maize mixed, agropastoral, highland perennial and highland mixed farming systems.

A focus on the development actions listed in Table 18.3 would contribute to improved food security. Small and large tractors and combine harvesters, with supporting equipment such as no-till drills and small power units (fossil fuel and increasingly electric) will boost returns to farm labour and reduce women's workload. All forms of rural electrification will facilitate intensification and diversification, especially through community-managed renewable energy production with storage (solar, biomass, micro-hydro, wind). The traditional programmes for fuel-efficient stoves are still relevant, leading to reduced biomass use and positive health outcomes. In the medium term, support for solar-powered options for water lifting and other tasks could transform farm household productivity and lives.

Additional energy through small power units is a critical input to water pumping, crop and livestock intensification, and food processing, and in facilitating the mechanization of production, storage and transportation – with consequent increased income and returns to labour. Electrification from the grid, or from local community-managed renewable energy production, especially when combined with low-cost storage, underpins communications and the delivery of health and educational services. As noted in Box 18.4, emerging renewable energy technologies open up opportunities for farm and community diversification to produce local energy as an income source. Distributed energy production combined with low-cost storage would be especially valuable in remote communities in the pastoral farming systems, in some fish-based system areas and in the forest-based system – while facilitating intensification and diversification in the medium and high potential systems.

The two main challenges are to increase energy consumption and efficiency. There are many dimensions to energy use. In cultivated systems, the development and promotion of labour-saving technologies and equipment to release child labour for schooling, and adult labour to address other labour bottlenecks, is important. There is ample scope to promote resource-saving technology (food preparation and crop processing). To counter biomass shortages, further expansion of farmer-managed natural regeneration, community woodlots and other agroforestry practices for fuelwood and charcoal production is needed.

Box 18.4 Distributed bioenergy and renewables production

In general, energy availability is a major determinant of sustainable development. In Africa, increased energy use will be a critical driver of intensification of food production, storage and processing, and sustainable development. Without doubt, the share of renewables will increase and it is probable that there will be a tendency towards distributed production and consumption (micro-grids). Africa has a comparative advantage, yet to be exploited, in bioenergy production, including second-generation bioethanol production from agricultural wastes, pasture and crop residues. Small-scale distributed production is technically feasible and has the potential to bring additional income and energy to remote populations. Solar and wind power technologies have developed rapidly, and can also be used for small-scale production and at community level, through micro-grids. Along with the recent breakthroughs in low-cost battery storage, these new renewable technologies could herald a revolution in distributed energy production – as a foundation for a low carbon economy.

The improved local availability of bioenergy would maintain nutrients in fields and reduce pressure on natural forests. Governments have begun to increase attention on local and renewable energy sources. Such promotion of alternative energy sources for urban and rural demand as a top priority will accelerate rural development and the achievement of food security (especially for highland mixed, pastoral, and arid pastoral and oasis systems). The opportunities of opening energy markets to private sector investment in remote areas such as the Sahara desert should be considered.

Natural resources and climate

In many farming systems, variable annual rainfall, poor soil quality and drought create a challenging agroecological environment. Climate variability is causing extreme events, particularly floods, thus affecting resources and livelihoods. These result in highly variable crop yields, a high risk of crop failure and a great year-to-year variation in pasture or fodder for livestock. This is particularly true in the cereal-root crop mixed, pastoral and agropastoral farming systems. Declining soil fertility and declining biodiversity, along with serious land degradation, have become major development concerns in all farming systems. There is major evidence of declining biomass productivity, which is a critical, relatively new, challenge on a huge scale in Africa.

Most farmers use little or no fertilizer, due to its high costs or inadequate returns. They may also be applying decreasing amounts of manure, compost and organics because of the increasing opportunity costs of family labour. Fertilizer use will increase over the coming decades, most likely with an emphasis on nitrogen, leading to an imbalance in major nutrient applications and to emerging minor nutrient deficiencies, for example zinc and sulphur. This calls for soil fertility management strategies that rely on better on-farm integration of livestock and fertility-enhancing trees, resource-conserving agriculture and better access to balanced fertilizers (Box 18.5).

Box 18.5 Sustainable and resilient intensification

There is gathering momentum behind the strategy and approach of sustainable intensification, in order to boost food production to feed Africa in 2050. The approach is particularly applicable to Africa, with its enormous capacity to contribute to the global food systems (FAO 2011; FARA 2014). Sustainable intensification aligns well with the sustainable development goals. The emphasis on resource management and productivity leads naturally to new approaches such as conservation agriculture, reduced tillage, maintaining ground cover and crop rotations (now referred to as CASI – conservation agriculture-based sustainable intensification). Such steps towards transformation and away from the incremental intensification of existing technologies will be necessary to reverse or avoid the current resource-degrading development pathways.

The elements listed in Table 18.3 would contribute to improved land, water, and tree condition and productivity. An emphasis on sustainable resource management and production (and consumption) would underpin sustainable and resilient farming systems intensification. The focus also needs to shift from food production on expanded cropping areas to yield intensification, with important implications for information and farm management. There is huge potential from groundwater use, but it needs to be managed smartly and cautiously – to avoid the depletion experienced by other continents. Development actions are required to increase the proportion of perennials in all farming systems. As with technologies for food production, there are pay-offs to intensification, diversification and sustainability from integrated approaches to resource management and restoration. Naturally, a focus on climate-smart agriculture and adaptation to climate variability will increase resilience of the systems.

Recent deforestation has particularly occurred in the forest-based, tree crop, root and tuber, and cereal-root crop mixed farming systems. However, biomass productivity has increased in some parts of west Africa during recent decades, particularly in the agropastoral and cereal-root crop mixed farming systems, partly due to the widespread adoption of farmer-managed natural regeneration of trees in croplands.

Water management offers great potential for agricultural growth, and for reducing food insecurity and poverty in SSA. Irrigated farming occupies less than one-fifth of the estimated suitable area, so this could be dramatically increased. However, large-scale irrigation through public investment has often failed.

Smallholder irrigation is widespread, and rainwater harvesting technologies are available for vast expansion – both should be strongly promoted. Tsetse fly infestation has been a major, albeit declining factor, limiting the distribution of livestock in some farming systems, for example in the cereal-root crop mixed farming system.

Climate change is forecast to have some of its most severe effects in parts of Africa, and the uptake of adaptive farming systems is a key challenge for the future. With higher temperatures and rainfall variability, farmlands will be more susceptible to reduced yields and will have a lower yield potential. The effects are already apparent in the agropastoral systems in southern Africa.

Nearly every farming system analysis has signalled widespread land degradation combined with low productivity. The goal of sustainable intensification is to address this widespread land degradation, declining soil fertility, and low crop and livestock productivity (Box 18.5).

The frame for sustainable intensification should be the food-energy-water nexus, including improved upstream-downstream relationships. Elements include improved cultivars, improved breeds, livestock feeds and veterinary products. There is an important set of management practices around water harvesting and small-scale irrigation, anti-erosion designs and field boundary plantings. The water harvesting and small-scale irrigation solutions apply to all of the subhumid and semi-arid farming systems, such as the agropastoral and cereal-root crops system. Some best practices in rainwater management could be sought from other sub-continent (e.g. South Asia).

Another set of management practices relates to integrated soil fertility management and judicious use of balanced inputs supporting local farmer experimentation. Improved seed systems are also needed by the cropping systems. These may be private sector driven where there is a commercial value proposition, for example hybrid maize. Otherwise, they may be community based, for example, seeds of legume crops. Improved range management will address pastoral system needs, as would multi-stakeholder transhumance corridors for livestock management.

All systems would benefit from public action to support integrated participatory natural resource management. This could include individual and collective actions at watershed scale including local byelaws, for example in the highland mixed system, and crop-livestock integration in the majority of systems. Similarly, agroforestry and parkland regeneration is applicable to many African systems.

More generally, public support for documenting, celebrating and replicating success stories in landscape rehabilitation would accelerate the rate of innovation and spread. Clearly, emphasis on climate change adaptation should occur in all systems (Box 18.6) but could take different directions in each.

Box 18.6 Targeting climate-smart agriculture

Climate-smart agriculture (CSA) is an approach which responds to the constraints of, and opportunities from, climate change. Providing agro-meteorological services and enhancing farmers' capacity in planning climate-proof management practices is expected to pay a large dividend to smallholders. There are opportunities for relay cropping and fodder production in crop-livestock systems, and adaptation to increased climatic variability through 'response farming', which adjusts planting dates and management conditions to suit the particular season. It embraces smart intensification and diversification. Climate change will drive greater emphasis on trees and shrubs in farming systems, both because they are more resilient to frequent and severe drought, and because they can provide a buffer against drought and higher temperatures for annual crops. The farming systems framework provides a structure for elucidating differentiated strategies for planning and monitoring CSA technologies and programmes.

Population, food security and poverty

Despite some possibilities for area expansion, farming systems are reaching limits due to rapid population growth. The result has been reduced farm sizes and the fragmentation of farms. As households sought to provide food and maintain their income levels, other

changes have occurred including shorter or eliminated fallows, reduced soil fertility and soil degradation. Off-farm work is now a significant and growing component of household income generation in most farming systems. Urban populations have expanded due to rural displacement, creating an expanding demand for rural produce.

Close to three-quarters of rural poor live in five farming systems: maize mixed, agropastoral, highland perennial, root and tuber crop, and cereal-root crop mixed. By and large, changes in these systems are being driven by strengthening access to services especially markets, closure of the land frontier and declining farm size. These changes have exacerbated poverty, food insecurity and have accelerated social change. An exception is the cereal-root crop mixed farming system, where there is still opportunity to expand into unused land, if constraints with markets, transport and storage of produce can be ameliorated.

Three development actions, listed in Table 18.3, merit particular attention. The availability of quality schooling, especially for farm girls, will ultimately reduce inequality. School curricula should be linked to the specific farming skills for each farming system, especially in relation to diversification crops and livestock. There is a need for a strong focus on youth in farming (training, credit, groups), including town employment schemes in agrivalue chains, to absorb household labour or enable an exit from agriculture. Bearing in mind the expected changes in farming systems in the coming years, a focus on labour-efficient and labour-saving technologies and institutions will have high pay-offs.

Schooling is critical not only for the future farmers, who will manage more complex and commercialized farms, but also to equip boys and girls with the knowledge and skills to compete in the off-farm labour markets – whether part-time or full-time. For the future farmers, incorporation of farming into the curriculum would be effective and motivational. Remote areas are a particular challenge for the provision of schooling services. Some of this gap could be filled by targeted radio and ICTs.

There is a youth bulge in the demographic profiles of most African countries, whereby youths represent about 60 per cent of the population. If government invests in education and business start-ups, youth may represent a productive resource for potential improvement in food security. The provision of remunerative and satisfying alternatives to the farm youth would ameliorate the population pressure on cultivated land. Mobility of youth and older members of farm families to other farming systems or to towns and cities is also important for intersectoral transfer of surplus labour and to provide better opportunities for migrants to secure gainful employment. Such migration should be facilitated by legal and safe travel and good information on employment opportunities.

Low levels of food and nutrition security greatly influence household strategies (see previous section) and farm management decisions that favour reliable food crops and small ruminants and poultry. Farm enterprise choices expand as the family size reduces and the immediate food requirements diminish and household incomes rise. Human health and epidemics also shape farming system possibilities, for example HIV or malaria – and for this reason public health programmes also enable farming systems to contribute to the potential improvements in food and nutrition security.

Enabling implementation through selective targeting to farming systems

Rural food and nutrition security is one of many policy objectives; others often include agricultural exports, balance-of-payments, urban food prices and improved environment

and other goals related to sustainable development. Arguably food and nutrition security is a high priority objective for African countries – and its achievement contributes to other policy goals – therefore this analysis should be of considerable value to many policy makers.

As noted in Chapter 1, the analysis of farming systems is not confined to households or household types. Rather, the analysis takes account of the local institutional environment, including the various linkages between, and movement to and from, other farming systems. Local value-addition is also considered, including those parts of value chains which interface with farmers and communities that contribute to forward and backward linkages among farmers, value chains and the non-farm economy. These linkages underpin the economic multipliers between the farm economy and the rural non-farm economy, which contribute to rural employment and non-farm economy growth.

There is general recognition that implementation failures for strategies and policies are common. Many factors may contribute to implementation failures. Based on this experience, it is worth noting several factors associated with successful implementation of policies and programmes. First, those strategy or policy instruments which fit well with the farming system characteristics and farm household strategies are often effective and lead to the desired outcomes. Second, adequate coordination of stakeholder engagement in space and time, notably public and private sector services, promotes the effectiveness of programmes (Abate et al. 2015). Third, successful implementation is associated with adequate understanding by programme staff of system interactions, for example the interaction between producers with markets, or the interactions of crops and livestock on mixed farms. There is a need for educational and training opportunities in systems development approaches at all levels. Fourth, successful programmes generally have ‘smart’ monitoring, evaluation and learning activities which inform adaptive management of the programmes depending on evolving circumstances (droughts, market prices, stakeholder conflicts).

Coordination and harmonization of services and programmes is most effective in a decentralized context where a participatory approach is adopted. For example, the coordination of agricultural services (through innovation platforms or other local multi-stakeholder fora integration), along with increasing the social and institutional capital, ensures linkages and harmonization across communities, research, extension and businesses, and between biophysical and social sciences.

In relation to stakeholders, capacity for increased farm and common property management is important to underpin participatory engagement with other stakeholders. Civil society organizations can play or foster the critical, local, bridging functions (the ‘last mile’) required between farmers and value chains. Increasingly, micro- and small businesses are the priority need in many communities; these not only facilitate inputs and produce flows to market but also add local value, provide information to producers, buffer risk and create employment, thereby adding to local farm/non-farm economic multipliers. Larger agribusinesses link the rural economies to domestic markets, regional trade and international markets. Governments play a lead role in facilitating stakeholder engagement, setting the policy framework and creating the institutions and incentives to encourage sustainable and resilient intensification.

In order to facilitate successful implementation, the strategies and policies need to be broadly consistent with farming system characteristics and needs, and the implementation programmes need to be targeted and adjusted to relevant farming systems. More country-level applications of the farming system framework would provide critical information to the National Agricultural Investment Plans. The adoption of the farming system

framework by regional and subregional organizations (including African Union, NEPAD, Africa Development Bank) and national research and policy units would complement the lead taken by FARA in incorporating the framework in the Africa Science Agenda.

References

- Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., Kassie, M., Bogale, G., Tadesse B. and Keno T. (2015) Factors that transformed maize productivity in Ethiopia. *Food Security* 7: 965–981.
- AGRA (2017) *Africa Agriculture Status Report: The Business of Smallholder Agriculture in Sub-Saharan Africa* (Issue 5). Nairobi, Kenya: Alliance for a Green Revolution in Africa.
- Amede, T., Auricht, C., Boffa, J.-M., Dixon, J., Mallawaarachchi, T., Rukuni, M. and Teckleworld-Deneke, T. (2017) *A Farming Systems Framework for Investment Planning and Priority Setting in Ethiopia*. ACIAR Technical Report 92, Canberra.
- Dixon, J. (2006) *Module 4: Investments in Sustainable Agricultural Intensification*. *Agricultural Investment Sourcebook*. World Bank.
- Dixon, J., Gulliver, A. and Gibbon, D. (2001) *Farming Systems and Poverty. Improving Farmer's Livelihoods in a Changing World*. FAO and World Bank, www.fao.org/farmingsystems/.
- Dror, I., Cadilhon, J.-J., Schut, M., Misiko, M. and Maheshwari, S. (eds) (2016) *Innovation Platforms for Agricultural Development: Evaluating the Mature Innovation Platforms Landscape*. Routledge.
- FAO (2011) *Save and Grow: A Policy Makers Guide to the Sustainable Intensification of Smallholder Crop Production*. FAO.
- FARA (2014) *Science Agenda for Agriculture in Africa: Connecting Science to Transform Agriculture in Africa*. FARA.
- Faurès, J.-M. and Santini, G. (2008) *Water and the Rural Poor: Interventions for Improving Livelihoods in Sub-Saharan Africa*. FAO and IFAD.
- Fischer, R.A. and Connor, D.J. (2018) Issues for cropping and agricultural science in the next 20 years. *Field Crops Research* 222: 121–142.
- InterAcademy Council (2004) *Realizing the Promise and Potential of African Agriculture*. InterAcademy Council, Amsterdam.
- Jayne, T.S., Mason, N.M., Burke, W.J. and Arigac, J. (2018) Review: Taking stock of Africa's second-generation agricultural input subsidy programs. *Food Policy* 75: 1–14.
- Makini, F.W., Kamau, G.K., Makelo, M.N., Adekunle, W., Mburathi, G.K., Misiko, M., Pali, P. and Dixon, J. (2013) *Operational Field Guide for Developing and Managing Local Agricultural Innovation Platforms*. KARI-ACIAR-AusAID, Nairobi.
- Qureshi, M.E., Dixon, J. and Wood, M. (2015) Public policies for improving food and nutrition security at different scales. *Food Security* 7: 393–403.
- van Ittersum, M.K. et al. (2016) Can sub-Saharan Africa feed itself? *PNAS* 113(52): 14964–14969.
- van Velthuisen, H., Fischer, G. and Hizsnyik, E. (2013) *Technical Annex: FS Characterization with GAEZ Data – The African Farming Systems Update Project*. IIASA, Laxenburg.

19 Conclusions

Implementation of the farming systems approach for African food security

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Key messages

- The vision is that, by 2030, market-oriented diversified small farms will dominate African agriculture, linked to and supported by value addition and agroprocessing by small- and medium-sized enterprises in value chains that create jobs for young people and women. These farming and food systems will provide rural food and nutrition security and underpin adequate and diversified food supplies to cities.
- Sustainable intensification and diversification will underpin functional farming and food systems with greater resilience to climate and market shocks as well as rural transformation in Africa.
- Knowledge of farming systems (defined broadly to include value chains and local institutions) and farming systems thinking will strengthen decision making through the critical analysis of required policies, institutions, innovations and investments for rural development. Focused knowledge sharing and systems analysis by major farming systems will be enabled by the establishment of multi-stakeholder consultative platforms for important farming systems, supported by existing regional and national bodies.
- Increased capacity in systems analysis at all levels is needed to enable the formulation of effective integrated strategies, implementation and monitoring of impacts. Capacity development will be supported by centres of excellence on farming systems research and development.

Summary

With a growing population, changing demands and strengthening food markets in Africa, it is expected that semi-commercial and commercial diversified small and medium-sized farms will dominate agriculture by 2030. Increasing commercialization has already modified farming systems during the period from 2000 to 2015, along with new technologies, feeder roads and markets which changed crop, livestock and livelihood patterns. The continued evolution of the agricultural sector to 2030 will stimulate rural transformation, with a vibrant rural non-farm economy well linked to farming and urban economies. Progress in African farming and food systems will be largely driven by sustainable intensification and diversification of smallholders. Agribusiness will provide affordable services

to farmers, value addition and access to domestic and export markets. Farming and food systems will be resilient to climatic and market shocks.

A greater understanding of farmer and rural entrepreneurial decision making will contribute significantly to co-designed, inclusive policies and institutions. These will include elements that are customized to specific farming systems. To this end, regional and national multi-stakeholder farming systems platforms are needed to coordinate the analysis, monitoring and evaluation of farming systems structure and function, and to inform policy formulation and investment planning accordingly. The platform teams will integrate the knowledge and views of Ministries, producers and value chain actors, in order to tailor policy formulation, research priorities and rural development investment to specific farming systems.

This vision of farming and rural and food system development will require a massive boost in the capacity to conduct systems analysis and participatory engagement. The use of systems modelling tools enables researchers and policy makers to identify strategies and points of intervention in farms and value chains that result in the greatest returns for the lowest risk. There is a great need for retooling to undertake multidisciplinary analyses of important farming and food systems. Hence building capacity to undertake systems analyses within and across development agencies is a high priority, which should be supported by centres of excellence on farming systems research and development. Successful expansion of systems analysis will require strong commitment and leadership in individual countries and at regional levels.

The vision for farm households, farming systems and food systems in 2030

This book updates the 2001 FAO/World Bank study of farming systems and poverty (Dixon et al. 2001) for Africa, taking into consideration increased population, evolving demands for food, changing climates, strengthening markets, new technologies and other mega-drivers of change. Previous chapters documented a wealth of knowledge on the resources, livelihood patterns, performance, drivers, trends and strategic interventions in African farming systems which can improve food and nutrition security by 2030. Chapter 1 introduced African development challenges, supply and demand for food, poverty reduction, mega-drivers of agricultural and rural development, and the livelihood patterns characterizing various African farming systems. Chapter 2 outlined the sources of information and the methods of data triangulation and analysis. Each of Chapters 3 to 16 characterized a particular farming system and its subsystems, summarized system performance, outlined the influences of the mega-drivers of change and identified priority strategic interventions. The potential advances in farming and food systems were sketched out in Chapter 17, laying the foundation for a discussion in Chapter 18 of key elements of national and regional strategies for improved food and nutrition security.

The farming system concept applied throughout this book embraces the management of plant, animal and other farm production and household consumption, and the function of local institutions associated with value chains, market access, community groups and common property resource management, including forests, grazing lands and water resources for irrigation and livestock. The analysis of farming systems identifies a wide range of interactions between the elements of farms, households and local institutions. Such interactions are frequently synergistic. For example, fertilizer trees generally increase

soil fertility and food crop yields, contract farming can strengthen production and markets, diversification of farm crop and livestock enterprises can improve household diets and reduce malnutrition, and the adoption of conservation agriculture can reduce women's labour requirements. In other circumstances where interactions are competitive, the analysis of trade-offs is important. For example, the consumption of crop residues by livestock might slow the adoption of full conservation agriculture practices, strengthened value chains might weaken traditional local exchange mechanisms, or availability of cheap inorganic fertilizer might reduce applications of compost to crops. The concept of food systems embraces all activities from food production to consumption, and thus overlaps the farming system concept. Food value chains, markets, quality and nutritional outcomes are important aspects. Sustainable farming and food systems ensure improved smallholder incomes and food and nutrition security for consumers (including smallholders) while meeting environmental, economic and social goals. Smallholders, rural communities, consumers and national economies can benefit from farming and food systems analysis which improves policies, institutions, markets and technologies.

This chapter outlines an achievable vision of farming and food systems development, in line with the Malabo Declaration and the Sustainable Development Goals, based on the implementation of the interventions and policies identified in this book. We envisage, by 2030, an African agriculture which will be dominated by market-oriented small- to medium-sized family farms with diversified and semi-commercialized crop, tree, livestock and fish enterprises. Within each broad regional farming system there will be pockets of advanced rural development with leading innovative households who manage integrated farms with novel diversification and substantial off-farm income – from which other farm women and men will learn. Rural youth will play a critical role in the modernization of the farming, non-farm and food systems. Many leading smallholders will have been able to expand cultivated area and herds through leasing, out-grower schemes and other institutional arrangements, and be well connected to local and urban markets. Many farmers in most systems will benefit from the expansion of small-scale irrigation, conservation agriculture-based sustainable intensification and diversification, fodder management and agroforestry tree cover on farms. Modern information technologies will be one driver of change, supported by remote sensing and spatial analysis technology, early warning systems, and knowledge of biotechnologies and biological control and management of pests, weeds and resources. Consumers will benefit from improved food systems, particularly diversified and reliable food supplies to cities.

Because of more effective agricultural services provision, made possible by increased public and private sector investment, leading farm households will be well informed about market, regulatory and technological options. They will invest in their farm resources and benefit from better farm management supplemented by active learning and innovation. They will also benefit from advances in social capital, for example, through rural women and youth groups learning about institutional and technological innovations to improve resources, productivity, market access and resilience to climatic, disease, market or other shocks. Wide availability of food market information will benefit smallholder producers and rural and urban consumers.

Functional and equitable local institutions and policies will enable flow-on benefits to the wider community and rural population. Improved agricultural services and market access will underpin intensification, diversification and increased off-farm income. Through a greater diversity of farm enterprises and increased local income, household

food and nutrition security will be substantially improved in many rural areas and for urban consumers. In addition, greater incentives for sustainable land and water management will be demonstrated through active land restoration programmes. Successful innovation platforms or other forms of multi-stakeholder consultation will bring together local value chain agents, farmers, researchers, extension specialists, NGOs and local development officials. They will actively foster accelerated technological and institutional innovation that better meet farm resource management needs, and facilitate more effective, equitable and productive local common property resource management.

The successful smallholders will be embedded within flourishing farm and non-farm rural economies that will generate enough additional employment to slow migration to megacities. Digitally supported competitive markets will enhance the availability of a wide range of timely and affordable supply of inputs including finances, insurance and information services, and attract investment in transport and value addition for local produce to domestic, African and international markets. In addition, improved rural labour markets will expand opportunities for off-farm employment, link smallholders to rural business and increase growth multipliers between the farm and non-farm economies.

African food systems will have expanded to adequately feed the growing rural and urban populations. Fertility rates are beginning to decline in many African countries, especially in urban areas. These will decline more rapidly, also in rural areas, as girls' education becomes ubiquitous, local health systems improve and economic growth generates opportunities for remunerative occupations. The next few decades are critical until population growth rates slow; thereafter, it will become easier to meet future food and nutrition demands through production and imports. Greater awareness of nutrition and diversification of farming systems are expected to alleviate the threats associated with the double burden of malnutrition.

Continuing urbanization will have generated many African megacities by 2030. Urban food demand will have increased very substantially, and urban consumers will be buying a much greater range of fruits, vegetables, dairy products and other higher-value foodstuffs. This trend will be a major stimulus to farmers and food value chains to provide a more diverse and profitable mix of food surpluses for supply to the cities. Smallholders and food value chains will be more competitive, and expanded subregional trade will drive increased efficiency, for the benefit of both consumers and farmers. However, the majority of smallholders will still consume a significant (although declining) part of their own home-produced food. Consequently, in the absence of perfect market function, farm household food consumption and production decisions will still be integrated. On-farm diversification will not only increase income and reduce vulnerability of livelihoods but will also underpin more diversified rural diets and reduce malnutrition. These changes in the food systems will be a major boost to the evolution of semi-commercial small- and medium-sized family farms.

The foregoing vision of farm households and farming systems development depends on the public and private sector stepping beyond business as usual. Effective implementation of improved and innovative food and nutrition security strategies that ensure more sustainable and resilient intensification and diversification will be absolutely critical. The consequence by 2030 would be substantial growth in average farm household income, a reduced proportion of food-insecure farm households and reduced rural malnutrition. The implementation of these better-targeted food and nutrition strategies will be facilitated by mainstreaming the farming systems framework and by enhancing systems analysis capacity in core agricultural and rural development organizations.

As documented in Chapter 18, the global farming systems framework has served many purposes since 2000 in relation to policy, investment planning, research prioritization and education for African farming and food systems. The update in this book of the status, trends and needs of farming systems in 2015 also adds enormous critical knowledge for much strategy development, planning, implementation, monitoring and evaluation. Chapter 18 also outlined the value of platforms and working groups for major African farming systems to monitor and evaluate trends, constraints, development initiatives, and emerging technological and market opportunities in the particular farming system. The clarification of the contrasting performance, constraints and needs of different farming systems will contribute to resolving the fundamental confusion which arises from averaging resource availabilities, yields, constraints and opportunities within a heterogeneous agricultural sector.

Implementation of the farming systems approach and food security strategies

Engaging with stakeholders

There are many stakeholders who determine the pathways for the development of farming and food systems, and they influence the outcomes of any agricultural or food strategy, policy or programme. There is a strong case for the reorientation and harmonization of stakeholder contributions. There are six main sets of stakeholders related to the development of farming and food systems: farm households, farmers groups and communities; rural and urban consumers; agribusinesses; national governments, their agencies and local officials; regional organizations; and development partners and other international investors.

As defined in this book, farming systems are groups of farmers (and communities) with similar livelihood patterns, constraints and development opportunities. The aggregate production and consumption outcomes of a farming system are a function of the decisions of millions of farm households, and careful analysis can anticipate the pathways of change and likely scenarios. The analysis in preceding chapters has shown that the potential of smallholders can be unlocked with access to public and private agricultural services including markets and new technological and institutional innovations. History shows that smallholders respond vigorously to incentives for farm development that are aligned with their own household strategies.

The growth of agribusiness in Africa has been slower than expected in the aftermath of the downsizing of public service provision during structural adjustment. However, there are now signs of agribusiness expansion in some sectors, for example in the marketing of improved maize seed. Also, farmers, farmer groups and communities are increasingly interacting with micro- and small businesses. The farming systems analyses can help to provide businesses with a better understanding of: the pathways for farming systems development, the development of markets for inputs to serve farm intensification and the needs of new enterprises for on-farm diversification. These farming systems analyses can help with optimal location of facilities, for example cold storage chains, fertilizer factories and processing units, and assist with feasibility studies and financing for agribusiness investment.

Alongside market development, national government agencies have a crucial role to play in the development of farming and food systems through the provision of critical public

goods such as technology, infrastructure, market and regulatory information, and the building of human and social capital. The targeting and delivery of these public goods will be facilitated by the further mapping and more detailed characterization of different farming systems at subnational levels. Moreover, the analysis of farm households and food systems provides knowledge on sustainable system options and farmer responses to policy instruments.

There is an important message for national agencies associated with integrated farming systems: interactions between trees, crops and livestock are so prevalent in Africa – they can be observed in the vast majority of farming and pastoralism situations – that farm household and community level interactions must be considered seriously in the design of agricultural development programmes and policies. Failure to understand these interactions and to incorporate this knowledge into programme design is in fact designing for failure. Indeed, this has been the key shortcoming that caused so many of the development failures that have been observed in the past.

Regional and sub-regional bodies can support national agencies with African regional public goods and links to international public goods. There is great scope for these managed spillovers of development options and experience within Africa and for learning from international experience. Better arrangements for regional trade in food between African countries will improve food system efficiency and reduce food wastage. As noted earlier, there is a need to expand the role of international public goods generated by international bodies, and for more active collaboration among these partners that is focused on farming systems as the basis for more successful food systems. Continental political organizations and institutions, if properly briefed, will be effective in reinforcing the efforts of sub-regional organizations for the coordination and scaling-out of the new innovations.

Engagement with stakeholders can occur individually but is often more effective through multi-stakeholder consultative processes such as the innovation platforms described in the previous section. In such innovation platform contexts, stakeholder interests can be aligned and conflicts can be resolved. These institutions can be organized at any level, from communities to farming systems or regions. For example, the farming system working groups discussed in the previous section could also bring together representatives of all six stakeholder groups at national or regional level for joint learning, coordinated implementation and monitoring of farming system developments.

Mainstreaming the farming systems framework into sustainable rural transformation and strengthened food systems

Farming and food systems are dynamic: they are continuously evolving and interacting. Part of the change is visible, but part is the invisible adjustments of internal economic and biological relationships which build up pressure for major change. The pressure points can be identified by careful analysis of the farming systems and the associated changes that are anticipated in coming years. Similarly, analysis can examine food markets and consumption and production trends. The path dependency of the evolution of a farming system is one important reason to classify and analyse current farming systems and their development pathways. In fact, many of the changes in African farming systems which occurred during the period from 2000 to 2015 were signalled in the 2001 FAO/World Bank analysis of farming systems (Dixon et al. 2001).

The African farming systems classification and approach has been incorporated into the Forum for Agricultural Research in Africa's Science Agenda. This update of the status,

trends and needs of farming systems in 2015 adds enormous knowledge for many development strategy, planning, implementation, monitoring and evaluation processes. This idea could be further developed by the establishment of platforms and working groups for major African farming systems, in order to monitor and evaluate trends, constraints, development initiatives and emerging opportunities in the target farming systems. Such platforms not only bring together key stakeholders from the public and private sectors but also would generate valuable knowledge bases in relation to each farming system.

Africa has a long tradition of establishing public initiatives for marginal agricultural sectors, for example the Arid and Semi-arid Lands policy (ASAL) in Kenya. Regional research organizations and the CGIAR recognized different agroecologies for targeting research. However, farming can no longer be differentiated merely by agroecologies because of the huge influence of agricultural services, especially markets. In reality, targeting by agroecological environment largely ignores the importance of socioeconomic factors as determinants of farming systems and the likelihood of innovations fitting the systems. Thus, there will be great value in the establishment of farming systems platforms and working groups at national and regional levels. Essentially these are an institutional innovation which bridges local knowledge with big data, and it strengthens the role of practical, actionable knowledge in public policy and planning. These platforms would be relatively low cost and would coordinate and concentrate studies, establish knowledge banks, monitor innovations and performance and, optionally, coordinate the delivery of critical services where coordination is essential. The sub-regional research, development or policy organizations based in the relevant regions could be mandated to monitor and oversee the quality of the work of the groups, particularly in the formative stages.

Capacity building for farming and food systems in Africa

The analyses in this book illustrate that weak capacity of many local actors hinders positive change, especially in terms of integration and interdisciplinary engagement. Moreover, most scientists and policy makers are well trained in disciplinary skills, but often they lack exposure to and confidence in systems thinking and analysis. Because integrated farming and food systems are dominant in Africa, there is an urgent need to develop systems analysis capacity to complement the disciplinary skill sets within public and private development entities.

The development of systems capacity could be led by regional or national centres of excellence which support universities and training centres in enriching curricula and building staff competencies in systems analysis skills. There is a range of systems methods that could be productively deployed, including soft systems, transdisciplinary analysis, foresight approaches, resource and farming systems modelling and multi-market analyses to assess the resilience of climate-smart agricultural practices. Farming and food systems would be priority themes for the application of systems studies.

Many of the stakeholders mentioned earlier could benefit from capacity building initiatives. The knowledge of staff of government agencies, including extension, could be updated in relation to technologies, systems analysis and participatory methods. Farmer groups could be trained in practices to enhance farmer-to-farmer learning. An appreciation of farming systems by agribusinesses would facilitate targeting of product and market development.

Effective farming and food system strategies

This book has provided an overview of the principal farming systems of Africa and their interplay with mega-trends and drivers. It has highlighted a number of key opportunities for the improvement of farming systems and food policies and institutions. Drawing on these farming system analyses, the following paragraphs highlight critical elements for consideration by policy makers when formulating and implementing agricultural development and food and nutrition security strategies.

The perspectives shaping African public policies have evolved since the 1960s, as illustrated in Chapter 1. Clearly, the policy and institutional settings for improved farming and food systems will differ by country, and there is considerable scope for sharing experiences across countries. With the benefit of hindsight, we find that the gains from past agricultural, trade and economic liberalization in Africa have been less than expected, often patchy or limited and sometimes completely absent, for a variety of reasons. Poorer farmers lost the support once offered by (admittedly inefficient) parastatal marketing boards and government research and extension systems, but have often missed out on new subsidies, markets or production opportunities. The consequence has been continuing impoverishment for many, and growing rural inequalities between farmers who have gained and those who have been marginalized. Against this backdrop, there is a strong argument for deploying a mix of alternative strategies, central to which is overcoming local institutional failures and building social capital. The following paragraphs highlight some aspects of the elements of a regional food and nutrition security strategy that were proposed in Chapter 18.

First, reform is needed to address the institutional failures that are creating inappropriate incentives for poor resource management, production choices and value chain development. Institutions need to encourage synergies and manage conflicts between commodities and strategies – notably for sustainable management of land, water and forests – and encourage on-farm diversification alongside intensification. Labour markets and safety nets for the poor should be co-designed with agricultural programmes. Agricultural programmes should be predominantly area based rather than commodity based because of the links to rural transformation. No country has developed a food and nutrition security strategy without effective incentives for farm production and ongoing innovation.

Second, the key growth potential in agricultural trade and food markets lies in the expanding domestic and regional markets within Africa, where demand in some areas already far exceeds supply. Thus, enhancing these markets is the greatest opportunity to stimulate both the intensification and diversification of farming systems. This will boost rural incomes and food security, reduce urban dependency on food imports and pave the way for Africa to eventually compete as a food exporter on the world market. Such market access requires efficient value chains operated by entrepreneurs, which is a great opportunity for rural youth. On-farm diversification can improve diet diversity and reduce malnutrition, and therefore public agencies could encourage the development of value chains for diversification.

Third, there are huge development dividends from reducing the very large gaps in crop and livestock productivities, often 70–80 per cent of potential productivities. Existing technologies can be deployed to meet much of this productivity gap – with much more effective systems of scaling-up innovations. Each farming system would gain most from scaling up a specific bundle of sustainable technologies – with complementary institutions and markets. For example, crop and livestock producers' needs are quite distinct; root

crop, tree crop and cereal producers also require different technologies, market development and policies to enable effective poverty escape pathways. This will require a massive increase in national budgets for agricultural innovation and rebuilding the capacity for systems-adaptive research, including to address sustainability, diversification, nutritional and resilience goals. This is particularly critical if productivity gains are not going to be reversed due to the bite of climate change. Policy makers need to consider the major opportunity costs of not making these critical investments now.

Fourth, reducing the crop and livestock productivity gap means tackling the decline in soil fertility and land regeneration. A mixed strategy is needed based on integrated soil fertility management practices tailored to farming system conditions. The key water management lesson is the high payoffs from small-scale irrigation, improved soil water management and water harvesting. Before exploiting the huge groundwater reserves which have recently been identified, institutions need to be developed to prevent the groundwater depletion which is evident in the irrigated zones of Asia, the Middle East and the Americas.

Fifth, massive amounts of additional energy are required in African farming: for water lifting devices, farm operations, transportation and processing. In many cases this will require the decentralized production of renewables. The production of bioenergy crops and of local biomass electrical energy is a major potential source of energy as well as additional income for farmers.

Sixth, social capital and inclusive institutions (including women's empowerment) will be a game changer for farming systems and rural transformation by the 2030s. Multi-stakeholder innovation platforms will stimulate accelerated learning, innovation and connections to services and markets. This will require an investment in education and training, and making use of digital communications.

Seventh, rural populations have now reached critical levels in a number of farming systems, with the possible exception of parts of the agropastoral and pastoral systems. In many higher potential systems farm sizes have declined to levels that cannot sustain the minimal production and livelihood needs of farm households with current technologies, practices and markets. Migration to slums simply relocates the problem. Thus, opportunities for the development of rural employment and non-farm rural economies should be actively investigated. Appropriate development of farming systems can stimulate local value adding and can generate non-farm employment and business income through the farm and rural non-farm economic multipliers. There is a potential role for public policy and investment in the promotion of the non-farm rural employment generation, especially for youth, and rural economic growth.

This book has emphasized three scales of knowledge that may help decision makers better cope with the imponderables and the complexity of food and nutrition security. First, there are the larger trends and drivers that are in motion at the continental level, providing a macro-scale back drop and medium- to long-term context for policy and investment choices. Second, there is the level of the farming system, where the drivers play out in unique ways in the local resource and institutional contexts. Finally, there is the farm household itself and how it responds to internal and external forces, including policy interventions, food market changes and new technologies. We argue that a perspective which is deeply cognizant of, and knowledgeable about, all three of these scales and their interactions is fundamental to making and implementing successful decisions about African farming and food systems.

So, what are some key lessons that emerge from the systematic analysis of African farming systems for improved food and nutrition security, considering recent experience and the current possibilities? The positive predictions and forecasts of farming system change that are laid out in this book will depend on many factors, including external (for example, trade, international markets and climate) and internal (knowledge, capacity, institutional alliances, incentives and local stability). The investment in knowledge about important farming systems, and the analytical capacities to apply the farming systems framework and translate the results of farming systems analyses into effective policies and programmes, will generate large dividends. Policy formulation that is tightly grounded in context-specific knowledge of relevant farming systems will generally lead to better food and nutrition security, rural transformation and sustainable development outcomes.

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An improved knowledge of Africa's complex farming systems, set in their socio-economic and environmental context, is an essential ingredient to developing effective strategies for improving food and nutrition security.

This book systematically and comprehensively describes the characteristics, trends, drivers of change and strategic priorities for each of Africa's fifteen farming systems and their main subsystems. It shows how a farming systems perspective can be used to identify pathways to household food security and poverty reduction, and how strategic interventions may need to differ from one farming system to another. In the analysis, emphasis is placed on understanding farming systems drivers of change, trends and strategic priorities for science and policy.

Illustrated with full colour maps and photographs throughout, the volume provides a comprehensive and insightful analysis of Africa's farming systems and pathways for the future to improve food and nutrition security. The book is an essential follow-up to the seminal work *Farming Systems and Poverty* by Dixon and colleagues for the Food and Agriculture Organization (FAO) of the United Nations and the World Bank, published in 2001.

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