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

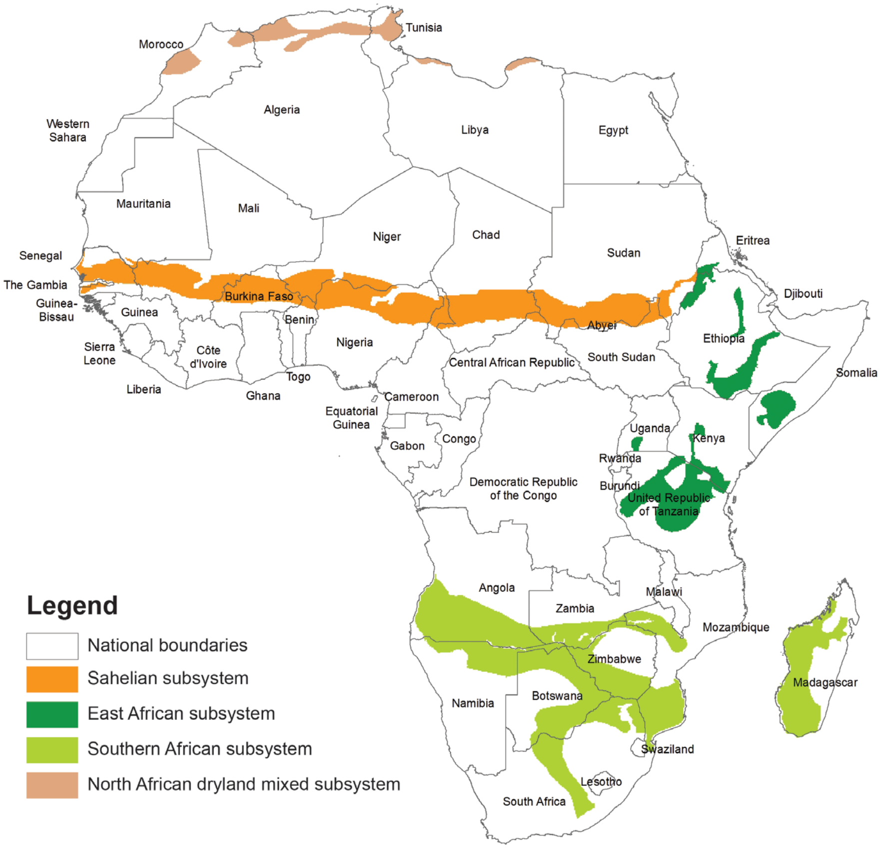

Figure 4.1 Map of the agropastoral farming system in Africa.

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 Mediterrean 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

Household wealth level	*Percentage of households*	*Household size*	*Cultivated area*	*Livestock assets*	*Ownership of draught animals and carts*
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.

Source: Household Economy Approach, Save the Children, 2009.

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

Subsystem characteristics	*Northern Africa*	*Sahel*	*Eastern Africa*	*Southern Africa*
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 (Diakité 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

Drivers of farming system change	*Trends*	*Key implications for farming system structure and function*
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) regreening 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	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.	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.
Markets and trade	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.	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.
Institutions and policies	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.	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.

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 djihadist 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

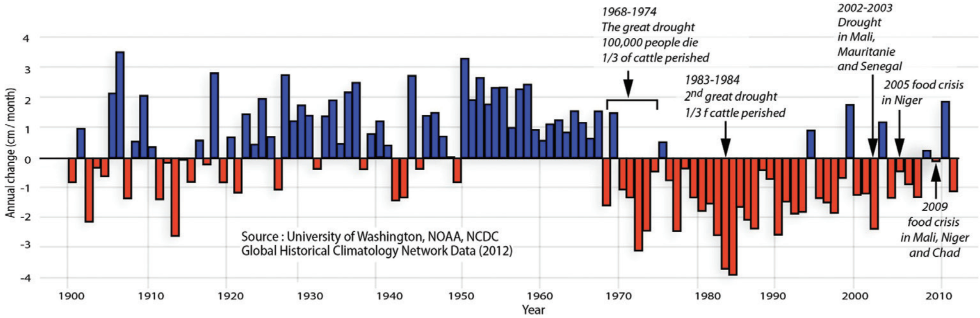

Figure 4.4 Variability of annual rainfall compared with average in the Sahel between 1900 and 2010.
Source: Nicholson et al. (2018).

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 (Diakité 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 (Kaboré 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, precut 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

Livelihood improvement strategy	*Extremely poor (2000)*	*Extremely poor (2015)*	*Less poor (2015)*	*Total agric. population (2015)*
% 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 Mukuna 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

Drivers of farming system evolution	*Strategic interventions*	*Implications for farming system structure and function*
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	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.	1) Socially more inclusive education; enhanced women's contribution to household livelihood; 2) increased capacity for intensification and diversification.
Energy	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.	1) Sustainable local fuelwood supply; 2) higher rural productivity; 3) lower urban demand for fuelwood.
Technology and science	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.	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	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.	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	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.	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.

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