7 The cereal-root crop mixed farming system

A potential bread basket transitioning to sustainable intensification

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Key messages

- The cereal-root crop mixed farming system is a potential food basket of west and central Africa, with an area of more than 200 million ha, good rainfall and an agricultural population of only 43 million.
- This crop-livestock system features a variety of cereals, legumes, cattle and small ruminants and has similarities to the maize mixed farming system in east and southern Africa.
- The main drivers of change are population increases and, recently, improving market access for grain and livestock.
- The long-term prospects for agricultural growth and sustainable intensification are excellent. There are great potential knowledge-intensive innovations such as mechanized conservation agriculture.
- Key enabling factors are transport infrastructure, enabling policies and farmer organizations to underpin market access and farmer-to-farmer learning and innovation.

Summary

The cereal-root crop mixed farming system has the most suitable climate in Africa for tropical cereals such as maize, sorghum and millet. Cereals and legumes are grown throughout the zone, usually intercropped, including with roots and tubers, vegetables and other crops. Cotton is more common in the north and root crops in the south.

Many farmers in the farming system use hand cultivation under rainfed conditions, with limited use of fertilizer. Animal traction is limited to areas where there has been successful commercialization of crops such as cotton and higher yielding maize composites. Tractor disc ploughing is increasing and is a concern for generally fragile soils. There is a lower population density compared with other farming systems in similar agroecologies, and medium farm sizes. However, rapidly increasing population densities are resulting in smaller farm sizes, increasing inequalities in land distribution and a widespread decline in soil health. As a result, traditional techniques of maintaining soil fertility are no longer sufficient to sustain food production. Moreover, there are continuing conflicts between
settled crop cultivators and nomadic Fulani cattle herders, though many Fulani have settled, managing mixed crop livestock systems. Despite the suitable agroecological conditions, 55 per cent of the population subsists on less than US$1.99 per day. While overall the farming system has been able to meet food requirements, a significant proportion of the population is undernourished and experiences food shortages during the hungry period (end of the dry season and beginning of the wet season). Migration to urban centres and for seasonal work in the forest-based farming system helps provide household remittances but is limited by job opportunities.

The farming system has undergone three key changes – increased area available for agriculture due to release of land from serious human and cattle disease, increased importance of some crops (maize, rice, soybean) and intensification of farming. Markets have emerged for the use of cereals (mostly maize) and cassava crops for commercial-scale production of livestock feed, starch and ethanol; soybean for feed stocks and vegetable oil; sorghum for beer; and vegetable crops for urban markets. Root and tuber crops, especially yams, remain mainstays. Increasing demand for food associated with rapid population increase, urbanization and changes in diet, offers opportunities for value-adding agricultural products, such as high value horticulture products, including potatoes, under irrigation in the cool dry season.

With its favourable climate and capacity to produce surpluses, the cereal-root crop mixed farming system has, for some time, been considered the future bread basket of Africa and has, historically, also been an important source of export earnings. While food production has previously been met through area expansion, the scope for further expansion is now limited. Intensification is the most feasible pathway out of poverty and to meet increased demand for food and improved livelihoods. Improved varieties, capacity building and more integrated sustainable farming techniques such as conservation agriculture (CA), agroforestry, integrated pest management (IPM) and integrated crop/livestock intensification are required to both improve soil conditions and meet the increasing demand for agricultural produce. Most of these innovations are knowledge and management intensive, and increased adoption will require investment in enabling environments and farmer learning.

Unlike in eastern and southern Africa where the system has changed to the maize mixed farming system, the development pathways for the current areas of cereal-root crop mixed farming system are likely to be different – involving increased mechanization (especially in west Africa), diversification including trees for wood and fuel, legumes, livestock intensification, and increased medium-scale agriculture in response to emerging markets and favourable agroecology. There are opportunities for agribusiness and private investment in seed inputs, purchasing, grain drying and storage facilities and feed mills, among others. Over time, the proportion of root crops may decline somewhat, unless use of cassava in livestock rations increases.

Well-targeted institutional support, along with public and private investment, is required to improve education, human capacity, transport and road infrastructure, regional employment opportunities, and provide credit, build the agribusiness skills of women, develop more efficient markets within and between farming systems and countries, and continue to manage tsetse, sleeping sickness, animal typanosomiasis and river blindness (Onchocerciasis) diseases. Promising cross-country initiatives such as Agriculture Growth Corridors as part of the public-private-sector partnership Grow Africa must be accompanied by national and local policies supportive of agriculture in the farming system, and equip households to adapt farming and livelihoods to drought, climate change and changing markets.
Governments must also play a greater role in mitigating agricultural land degradation and rehabilitating degraded landscapes in coming decades as greater pressures are put on the natural resource base. Trained service providers who conduct contract zero-tillage planting and appropriate herbicide application as part of integrated weed management strategies, and greater adoption of CA, will assist this. Research on locally specific adaptations of CA, and breeding and supply of locally suited soybean varieties, root, tuber, tree and vegetable crops is needed.

**Overall description of the farming system and subsystems**

*Basic description and importance*

The cereal-root crop mixed farming system (Figure 7.1) extends in a band across central Africa from Senegal and Guinea through northern Côte d’Ivoire to Ghana, Togo, Benin, Nigeria, northern Cameroon, the southern part of Chad, across the northern part of Central African Republic and southern Sudan.

The farming system has a warm tropical climate, an annual rainfall of 800 to 1200 mm, and a length of growing period ranging from 150 to 240 days. There is considerable excess of rainfall over evapotranspiration during the growing period so that the risk of severe drought is relatively low. However, devastating droughts have occurred in the past in the dry sub-humid parts of the zone, such as in 1930, 1972 and more recently.

The farming system is located between the agropastoral farming system to the north with rainfall less than 800 mm, and the root crop farming system to the south with more than 1200 mm rainfall. In Dixon et al. (2001), the cereal-root crop mixed farming system occurred in parts of southern, central and eastern Africa. However, as farmers increased the area of maize in the system during the period 2000–2015, in some areas the cereal-root crop mixed farming system has evolved into the maize mixed farming system while still retaining some small pockets with cassava, sweet potato, sorghum and millet (Chapter 3 this volume; IAC 2004).

*Figure 7.1* Map of the cereal-root crop mixed farming system and subsystems.

Source: GAEZ FAO/IIASA, FAOSTAT, Harvest Choice and expert opinion.
The cereal-root crop mixed farming system shares a number of system characteristics with the maize mixed farming system in eastern and southern Africa, particularly in the lowlands, but the cereal-root crop mixed farming system has a relatively lower population density, more unused cultivable land, higher livestock numbers per household and poorer transport and communication infrastructure. It also has higher temperatures and in some areas the presence of a tsetse challenge which limits livestock numbers and prevents the use of animal traction, particularly in the moist sub-humid zone (Dixon et al. 2001; FAO 2008). However, tsetse pressures are slowly diminishing as their habitat is increasingly disturbed by human activities.

In 2015 the total population of the cereal-root mixed farming system was 84.8 million, representing rapid annual growth since 2000, and estimated to grow to about 168 million by 2040. Approximately 50 per cent of the population were involved in agriculture (Table 7.1). Total cultivated area was 33.6 million ha, of which cereals (sorghum, millet, maize and rice) constituted two-thirds of the total, while root and tuber crops (cassava, sweet potato, yam) amounted to nearly 3 million ha, with annual leguminous crops or pulses (mostly cowpeas with some pigeon peas, dry beans) and oilseed crops (groundnut, soybean, sesame) comprising over 1 million ha and about 2 million ha respectively. Cotton accounted for nearly 1 million ha. Overall, there are about 0.14 total livestock units (TLU) per hectare and 3.7 TLU per household. These animal populations have increased over time.

In most of the countries, the farming system is regarded as the ‘grain’ belt and is often referred to as the ‘bread basket’. This is because the system has high agroecological potential for crop and livestock production, with the best moisture, solar radiation and thermal regime for tropical cereals such as maize, sorghum and millet. Soybean can be rotated with nearly all cereals in the farming system although with more difficulty in the areas with higher rainfall (unless sown to mature at the end of the rainy season). Future adoption of no-till CA systems will result in further increases of soybean in the 1000 to 1200 mm rainfall zones.

Table 7.1 Basic system data (2015): cereal-root crop mixed farming system

<table>
<thead>
<tr>
<th>Item</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total human population (million)</td>
<td>85</td>
</tr>
<tr>
<td>Agricultural population (million)</td>
<td>43</td>
</tr>
<tr>
<td>Total system area (million ha)</td>
<td>202</td>
</tr>
<tr>
<td>Cultivated area (million ha; % of total area)</td>
<td>33.6; 17</td>
</tr>
<tr>
<td>Irrigated area (million ha; % of cultivated area)</td>
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</tr>
<tr>
<td>Total livestock population (million TLU)</td>
<td>29</td>
</tr>
<tr>
<td>Major agroecological zone</td>
<td>Tropical warm subhumid</td>
</tr>
<tr>
<td>Length of growing period (average, days; core range, days)</td>
<td>187; 150–210</td>
</tr>
<tr>
<td>Access to services</td>
<td>Medium-high</td>
</tr>
<tr>
<td>Distance to 50k market (average, hr; core range, hr)</td>
<td>7.3; 2–10</td>
</tr>
<tr>
<td>Agricultural population density (persons/total area; persons/cultivated area)</td>
<td>0.2; 1.3</td>
</tr>
<tr>
<td>Livestock density (TLU/total area; TLU/cultivated area)</td>
<td>0.14; 0.9</td>
</tr>
<tr>
<td>Standard farm/herd size (cultivated area/household, TLU/household)</td>
<td>4.3 / 3.7</td>
</tr>
<tr>
<td>Extreme poverty (% of rural population)</td>
<td>55</td>
</tr>
</tbody>
</table>

Source: Refer to Table 2.4.
Staple cereals such as sorghum, millet, maize and upland rice, along with pulses (cowpeas and beans), oilseeds (groundnut and soybean), and root and tuber crops (cassava, yam and sweet potato), are widespread in the drier parts of this farming system. Although cereals and legumes, usually intercropped, are grown throughout the zone, cotton is more common in the north and root crops in the south. Crops are mainly grown under seasonal rainfed conditions in the uplands although some year-round cropping is found on the limited areas of lowland.

**Farming system structure**

Farming households traditionally only have usufruct rights to land (rights to use the land but no ownership or land title) under customary ownership or ‘Maliki’ law. The average farm is estimated to be 4.3 ha.

The average amount of land possessed by farming families is generally inversely related to population density. In areas of low population pressure, the amount of land farmed is in general a function of family size (labour force) and the quality of the land. As population density increases, the following changes take place: (i) farm size decreases with associated challenges with maintaining soil fertility; (ii) inequalities of land distribution often become an increasing problem; and (iii) as a result of smaller and increasingly fragmented farms, challenges with mechanization become greater. Considerable inequalities can arise in land distribution, which is often influenced by tribal leaders.

Inland valleys are natural drainage channels in the landscape, and they have a high agroecological potential because water is available or can be made available year round. Households often have two types of land, the upland fields known as *gona* or *gone* in Hausa and the hydromorphic land in the lowland inland valleys known as *fadama* in Hausa. As these two land types are often not adjoining, a household farm can have several separated fields of different quality, size and position in the landscape. Households manage this combination of land in the rainy and dry seasons, to produce a mixture of crops, livestock including fish, trees, as well as engaging in off-farm activities in order to satisfy household needs and fulfil cultural obligations.

In the *fadama*, wetland or flooded rainfed rice is a dominant crop along with yams, cassava and sugarcane, with banana away from the wetlands and bordering the nearby sloping and upland fields. Irrigated vegetable crops, including sweet potato and cassava leaf production, are common in the dry season in the inland valleys.

Households generally use hand tools to cultivate three to nine ha. The amount of land that can be weeded adequately by households during the seasonal weeding bottleneck period is an important determinant of the area cultivated. Modest use of herbicides in some cases is enabling farm families to expand cropping areas. Contract application of herbicide is increasing in Nigeria and Ghana, especially for weed control in cassava-based systems (F. Ekeleme of NRCC, pers. comm., 2014). Animal traction is often found in areas where there has been successful commercialization of a crop.

Intercropping is common and popular because of its advantages over sole cropping, which include yield stability and security and higher profitability due to higher combined returns per unit area of land (Box 7.1). Growing cassava with short-duration legumes supplies both carbohydrates and protein, which provides the foundation of a healthy diet for the farming household (Howeler et al. 2013). The mix of crops varies between regions (and households), as does the relative proportion of crops used for home consumption, livestock feed and sale.
Traditionally little mineral fertilizer is used. However, increasing numbers of households are applying small doses of fertilizer to the maize crop, especially in Nigeria and Ghana, and selling surplus production. The main sources of cash are cotton (in drier sub-zones), maize, cowpeas and vegetables. Increasingly, soybeans are found in the cropping system as a cash crop, in addition to some cassava and yam.

The household is largely food self-sufficient and sometimes has a small surplus to sell. However, poor households experience two to three months of food insecurity towards the end of the dry season and the early part of the rainy season (the so-called ‘hungry
season or gap’ or *soudure* in French). During the hungry season some farmers work for food on other farmers’ fields, although such work can delay planting and lowers potential productivity on their own fields. Further, many male household members, particularly of poorer households, migrate south to the forest-based farming system (Chapter 12 this volume) for casual work on plantations.

The main nutritional shortage in the ‘hungry gap’ period is protein, which in the dry subzone (north) is supplied mainly with millet, sorghum and maize grain which contain 8–14 per cent protein. Cowpea and groundnuts are important but lesser sources of protein due to their higher prices. To break the hungry gap in the wetter regions, maize for green-cobs and cultivars of early-flowering, day-length neutral, cowpeas are grown.

Roots and tubers remain mainstays and are an important source of nutrition and food security in the traditional mixed farming system. For example, Nigeria produces about 100 Mt/year of cassava and yam in this zone and Ghana produces over 20 Mt. Production of sweet potato (*Ipomoea batatas*) in Nigeria alone was about 3.5 Mt in 2013.

Beta-carotene-rich sweet potato varieties can provide a year-round, sustainable source of vitamin A in the diet in areas where children under five years old have significant levels of vitamin A deficiency. Yam tubers (*Dioscorea* species) tend to be higher in protein and minerals such as phosphorus and potassium than sweet potato roots, though the latter are richer in vitamins A and C. Unlike cassava, sweet potato and aroids (*Colocasia* species), the yam tubers can be stored for up to four to six months at ambient temperatures. This characteristic contributes to sustaining the food supply, especially in the food scarce period at the start of the wet season. At the farm level, cassava is stored by leaving it unharvested in the ground. Many important cultural values are attached to yam, especially during weddings and other social and religious ceremonies. In many farming communities in Nigeria and other west African countries, the size of yam enterprise is a reflection of one’s social status.

Throughout the farming system, households combine crop and livestock production. Livestock are an asset for high value income generation and risk management, in addition to their traditional role in providing manure for fertilizer. While not all farmers own cattle, nearly all farm households own a few chickens and goats.

The traditional approach involves free communal grazing after harvest, with herders from the agropastoral farming system moving through the cereal-root crop mixed farming system to graze on natural vegetation and crop residues, before selling animals in local markets and in urban markets in the more humid areas to the south. Both cattle and small ruminants are important. The crop-producing sedentary Hausa (and sometimes Fulani) farmers benefit from livestock manure in the crops, while herdsmen rely on crop residues for livestock feed during the dry season. In some cases herdsmen drive, fatten and sell in the urban centres in the south, animals that would not thrive during the long dry season. Crop residues are also frequently important for fattening of confined animals, including those raised for religious celebrations, such as goats for export to north Africa and the Middle East.

In recent years, there has been continued conflict between crop producers and livestock herders (Fulani) along some corridors. This has encouraged the settlement of some of the herders in areas where the tsetse fly is less of a problem. Such Fulani farmers are engaging in both crop and livestock production (Figure 7.2).

A recent trend among smallholders is to divide the herd at the end of the rainy season, keeping pregnant animals and important bulls and sending the less important animals south with the Fulani herdsmen. These animals are then returned to the farmer at the beginning of the next rainy season. Even more recently, the herd holder stays with the animals in the
The cereal-root crop mixed farming system

south (since the tsetse fly is now less problematic due to tree clearing and possibly climate change) where they are often sold, with the proceeds being remitted back to the animal owners. The process allows the owners to have larger herds and to be less restricted by the lack of dry season feed (J.E. Koneke, pers. comm., ILRI-Ibadan, Nigeria 2012).

Legumes are used for household consumption with some kept for seed and sale. Soybean is becoming the most important legume sold. Legume haulms are used primarily for livestock feed, and less often for compost or green manure. They are used for domestic animals and are sold for cash. In southern Kaduna State, Nigeria, where livestock densities are lower, the sale of residues is more common, mainly to traders from the north where peri-urban livestock keeping is increasing (Franke and de Wolf 2011).

The milk industry has historically been marginal, in part because of imported dehydrated milk (mostly from Europe). Traditional herders produce local cheeses, mostly for family use and sale in informal markets.

_Crop and livestock changes and intensification_

The farming system has undergone three key changes – increased area available for agriculture due to release of land from disease, increased importance of some crops (maize, soybean, rice) and intensification of farming and shortened fallows, if any (Figure 7.3).
Historically, the development of the farming systems was constrained by two major diseases, one affecting humans (Onchoceriasis) and one affecting animals (Trypanosomiasis). Onchoceriasis (river blindness) control efforts, especially in the 1980s, coupled with tsetse fly habitat disruption, have freed an estimated 25 million ha of cultivable land for agricultural intensification (World Bank 2009). The poultry and dairy sub-sectors in Nigeria and Ghana, as examples, have both nearly doubled since the early 2000s resulting in a growing feed demand and contributing to intensifying agriculture in the cereal-root crop mixed farming system.

There have also been substantial changes in the relative area of crops grown in some parts of the farming system over the last few decades. The shares of maize and soybean are expanding (World Bank 2009), as are small plantations of economically remunerative trees, such as smallholder teak, where land tenure is relatively secure. There are several examples in the farming system of successful development of niche products such sorghum for beer, and organic mangoes.

Maize, soybean and rice expansion

Maize has expanded north and has been promoted primarily as a sole crop to be sown with animal traction and fertilizer added. The substantial increase in maize farming over many decades reflects its much higher yield potential, changing consumer habits and

Figure 7.3 A soybean and maize plot in southwestern Burkina Faso under no-till management with a live fence introduced to control grazing of crop residues (fence seen on right side). Photograph taken during a farmer group appraisal.

Source: Eric Kueneman.
preferences (Norman et al. 1975; World Bank 2009) and its heavy promotion as the main staple cereal for the local population during the colonial period and during periods of humanitarian crises arising from natural disasters and political instability. Especially in the dry sub-humid parts, maize expanded as a result of the diffusion of improved early-maturing, fertilizer-responsive varieties, facilitated by fertilizer subsidies and production credit. Maize has been replacing sorghum for both food and feed.

The area of soybean has been expanding in countries where national economies are growing and diversifying, such as in Nigeria and Ghana, and where there is growing demand for locally formulated livestock feed and livestock products. Family farmers often intercrop soybean rows by replacing occasional maize rows with soybean. In some countries, governments promoted local soybean production by guaranteed prices until grain companies began sourcing locally rather than importing their supply.

Rice is an important crop in Africa and production, particularly of wetland rice in inland valleys, is expected to expand in the coming decades to meet the growing demand. Rice production in Nigeria rose from about 3 Mt to about 5 Mt from 2000 to 2012 (FAOSTAT), due largely to good support policies. As for maize, the economics of production depend in part on the costs of nitrogen fertilizer. Regional and national policies on fertilizer subsidies have, and will have in the future, major implications for production and productivity of these crops.

In many parts of the farming system in the south there are adequate growing days for two crops (cereals and legumes) per rainy season. However, energy costs for grain drying and storage of the first crop are currently a limiting factor, and without a strategy to dry grain or move it quickly to drier areas for sun drying, the potential for two crops per rainy season goes largely unrealized.

**Cotton expansion**

Cotton production is an important export-earning resource in many countries. In Burkina Faso, the largest seed cotton producer in Africa, the sector provides livelihoods to 350,000 cotton farmers and over 3 million people, with flow-on effects on trade, banking, the processing industry and transport – generally stimulating internal growth and generating tax revenue.

Some cotton farmers, particularly in the Francophone areas, are part of schemes operated by cotton companies, either fully private or partly public (i.e. parastatal). They follow a recommended package of practices with seed, fertilizer and pesticides made available to them by the companies to achieve satisfactory yields.

A multi-country, decade-long project in Francophone west Africa, implemented by FAO, is demonstrating important savings are possible through reduced use of pesticides in cotton. The project teaches IPM using farmer discovery processes and the Farmer Field School approach. This project and new Brazilian support to the same four major cotton countries in Francophone west Africa could make cotton increasingly attractive.

**Groundnut**

Groundnut production once flourished in the farming system in Nigeria and was a major export to Europe, but this collapsed in the late 1960s after the discovery of oil. Efforts to revive its production for export have been largely unsuccessful partly because of aflatoxin contamination of the grain. Aflatoxin is a powerful carcinogen. New approaches
(Aflasafe™) to controlling grain infection by *Aspergillus* (that produces the toxin) look promising and may help revive export markets. However, poor soil health linked to infestation by the parasitic weed *Alectra vogelli* results in poor groundnut productivity. If the aflatoxin issue is solved, export opportunities might justify the investments to overcome *Alectra* and other pests.

**Livestock**

Commercialization and intensification are changing the ways livestock are integrated into the farming system. Animal traction is being adopted, though sporadically, as a result of commercialized crop production (e.g. cotton and high yielding maize).

The integration of crop and livestock production is particularly apparent in intensively farmed and densely populated areas (Kamara et al. 2012). In recent years, where households have land in the inland valleys with a good year-round water supply and a source of fodder, dairy production has become an important commercial activity due to a higher and more reliable return on investment.

Recently, market integration has meant locally produced crop ingredients are used in livestock feed formulations (e.g. maize, soybean, cotton seed cake produced after cotton ginning) for intensive poultry and stall-fed livestock production including dairy (Fernández-Rivera et al. 2004; Thornton et al. 2002). Both the roots and leaves of root crops can be used as on-farm animal feed or as an ingredient in commercial animal feed. For example, before being fed to animals, cassava is chopped and spread out on a floor to wilt and is sun-dried to 12 to 14 per cent moisture content to release most of the cyanide content, making root chips and leaf pieces safe as feed for pigs, cattle, small ruminants and chickens (Howeler et al. 2013).

**Farming subsystems**

Two subsystems have been identified:

(1) The *cereal-pulse root crop subsystem* (subsystem 1) is located in the drier zone in the north, typically with 140–200 days length of growing period. The rainfall is reasonably reliable and functionally monomodal with one peak in August, making it suitable for intensive arable production. Sorghum, maize and millet are the dominant cereals, grown with or without cotton. Oilseeds such as soybean, sesame and groundnut, and pulses such as cowpea are frequently companion intercrops or in rotation with sorghum, millet and maize. In more favourable areas, root and tuber crops are grown, especially cassava and sweet potato in the uplands, and cassava and yam along the inland valleys where soil moisture is available beyond the rainy season. In this farming subsystem, important cash crops are cotton, millet, sorghum, maize, cowpea and groundnut. Cotton has been an important cash crop in the subsystem for centuries.

(2) The *root crop-cereal subsystem* (subsystem 2) is located in the moist sub-humid zone in the south, generally with 200–240 days length of growing period. There are two rainfall peaks in June and September separated by a relatively dry period in August, often referred to as the ‘little dry season’. The two growing seasons of unequal duration and this functionally bimodal rainfall regime make it more complicated for the drying of cereal and legume grains from crops sown at the onset of the first rains. One apparent trend associated with climate change is the reduction (near disappearance) of the short dry season in parts of the farming system.
Root and tuber crops such as cassava, sweet potato and yams are the most important staple crops. Cassava and yams are short-term perennials, while some cassava is left in the soil as a food reserve and a source of planting stakes. The roots and tubers are grown with maize and upland rice as well as pulses such as cowpea and oilseeds such as soybean and groundnut. These grain legumes are currently less significant, but in the future will increasingly become critical for income, soil health, pest management and human nutrition. Grain drying and storage facilities for food and oilseed legumes are generally inadequate in this humid zone.

Where the rainfall is functionally monomodal, soybean is becoming an important cash crop along with food crops such as maize, rice, cassava, yam and sugarcane, which is grown in lowland soils near rivers or other water sources.

**Household demographics, assets and occupation**

Table 7.2 summarizes farming system features at the household level by comparing Mali, Ghana and Nigeria. It shows an average household size of 7 to 22 with the household head 46–52 years old. The traditional extended family unit consists of more than one married man plus dependants, with most rural households in the farming system headed by males (e.g. 99 per cent in Kano and Katsina states, Nigeria). However, in Borno State, Nigeria, some 14.5 per cent of the households are headed by females (Amaza et al. 2009).

Almost all household heads are married, indicating the importance of family labour in this farming system. Traditionally, male household heads are responsible for most farm-level decision making (e.g. Nigeria, Ghana, Sikasso region; Fofana et al. 2011). Other household members are responsible for making farming decisions on specific fields. However, complex family units are increasingly breaking into simpler family units (one married man plus dependants) contributing in many areas to smaller farms, increased fragmentation of fields, younger, relatively inexperienced family heads and more diverse and decentralized decision making.

The occupational pattern is diverse and varies between regions and households. Sources of off-farm income include trading, operating a small business, handicraft, sale of charcoal and firewood, and remittances from urban employment.

Education levels are generally low. In Nigeria, 80 per cent of household members over 35 years of age have no background in formal education, whereas 40 per cent of the members between 17–35 years have some education with over 20 per cent reaching secondary level. In the Sikasso region of Mali, the household illiteracy rate is 59 per cent on average (Bamire et al. 2010). Males are generally better educated than women.

Farmer-based organizations are an important source of non-formal education and information about the type and availability of inputs and markets, group formation, farm planning and budgeting, sound agricultural practices, post-harvest management and marketing strategies. In southern Kaduna State, 50 to 65 per cent of the households belong to farmer associations such as cooperatives.

Traditionally, capital assets owned by farming families, apart from livestock, consisted largely of self-made goods, such as farm implements, tools and grain storage structures. The break up of families into simpler units is contributing to increased dependent-per-worker ratios, with resulting poorer net worth and cash liquidity levels.

Family members tend to provide most input on the family farm (Figure 7.4). However, seasonality of agriculture in this farming system creates two challenges: labour bottlenecks during the rainy season and underemployed labour during the dry season. Traditionally, most
Table 7.2 Farming system features at the household level

<table>
<thead>
<tr>
<th>Feature</th>
<th>Mali</th>
<th>Ghana</th>
<th>Nigeria</th>
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<tbody>
<tr>
<td>Family size (persons)</td>
<td>22</td>
<td>8.8</td>
<td>7.5</td>
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<tr>
<td>Age of head of family (yr)</td>
<td>52</td>
<td>46</td>
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</tr>
<tr>
<td>Males involved in farm work (%)</td>
<td>48</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Females involved in farm work (%)</td>
<td>67</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Literacy of heads of family (%)</td>
<td>41</td>
<td>6</td>
<td>48</td>
</tr>
<tr>
<td>Marital status of head (% married)</td>
<td>99</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>Cultivated area (ha)</td>
<td>9.5 (7–18)</td>
<td>3.9 (3–5)</td>
<td>8.7</td>
</tr>
<tr>
<td>Cereals (ha)</td>
<td>7.0</td>
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<tr>
<td>Grain legumes (ha)</td>
<td>1.0</td>
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<tr>
<td>Roots and tubers (ha)</td>
<td>&lt;0.1</td>
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<td>Cotton (ha)</td>
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<td>19</td>
</tr>
<tr>
<td>Small ruminants</td>
<td>15</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Poultry</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pigs</td>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Members of farmers’ organizations (%)</td>
<td>86</td>
<td>51</td>
<td>65</td>
</tr>
<tr>
<td>% hiring labour</td>
<td></td>
<td></td>
<td>58</td>
</tr>
<tr>
<td>% using mineral fertilizer</td>
<td>50</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>% accessing credit</td>
<td>81</td>
<td>17</td>
<td>27</td>
</tr>
</tbody>
</table>

Sources: Bamire et al. (2010); Fofana et al. (2011); Franke and de Wolf (2011); Wiredu et al. (2010).

Figure 7.4 Household compound in Karaba area, near Bobo Dioulasso, Burkina Faso.
Source: Amir Kassam.
explicit farm expenditures have been for payment of non-family labour. Such payment was often in-kind, although payment is now increasingly in cash, paid by the hour and job. This has led to attempts to introduce institutional forms of credit, both short and medium term.

**Trends and drivers of change across the farming system**

Farming systems tend to evolve depending on the interaction of agroecological, social, economic, technological, policy and institutional factors. McIntyre et al. (2009) and Norman (2002) asserted that first, agroecology, and second, population density, are the principal factors that create and drive the diversity of farming systems, after which market access (now of primary importance), land reforms and income, among others begin to exert significant influences.

**Population, hunger and poverty**

About half the population in this farming system lives in abject poverty. In 2015 about 55 per cent of the rural population had a per capita daily income of less than US$1.90.

At the household level, the rapid increase in population, decreasing farm size, increased inequality and farm intensification are often associated with a decline in soil condition and farm productivity. A significant proportion of the farm population living on 1–10 ha or less than 1 ha of land are undernourished or severely undernourished respectively (data from van Wesenbeeck and Merbis 2012).

Youth are seeking employment in urban areas. For example, in northern Kaduna, fewer younger people are entering farming; the majority are migrating to urban areas in search of better employment or business opportunities.

At the farming system level, in spite of the increase in population pressure, the farming system has been able to satisfy increases in food demand, and has been able to produce industrial raw materials such as cotton and, more recently, cassava for starch. The increase has been possible due to area expansion (increased cleared area), improved varieties and increased use of fertilizer inputs.

In effect, expansion has offset increased population and minimized/slowed the effect of decreasing farm size. While this farming system has more land available for further expansion than other farming systems in Africa, rapidly increasing population, declining soil fertility, occasional severe drought and lack of rural electrification, functional roads, health and finance services and education opportunities will constrain further expansion and intensification. Without change in farming practices, the prospects for meeting future food demands are of concern. This indicates that poverty and hunger will remain a problem in this farming system in the foreseeable future.

However, increased globalization and ‘prospectors’ looking for opportunities could accelerate change. Will farmers with experience in no-till-based tropical agriculture from southern Africa, Brazil or elsewhere begin developing farmlands in the high-potential savannas of west Africa? Policy makers need to consider such possibilities and their implications including the consequences for smallholders’ access to land. Some well-meaning farmers from outside west Africa are already establishing farms and experimenting.

**Natural resources and climate**

Deforestation has been extensive and is likely to continue as the farming system expands under pressure from population, markets and farm intensification. Within existing areas,
smaller farms and associated intensification of conventional tillage agriculture have had deleterious impacts on soil fertility and soil health. As a result, traditional techniques of maintaining soil fertility through shifting cultivation (slash and burn), ring cultivation and fallowing are no longer suitable to sustain food production. Additionally, responses to mineral fertilizers are less than optimum and insufficient plant biomass is produced to replenish the soil. Consequently, the current system is unlikely to be sustainable environmentally or socially in the longer run, especially given the anticipated negative impacts of climate change.

This problem is not unique to this farming system – across most production ecologies in Africa, including the zones with higher rainfall, soil degradation continues at an alarming rate as a consequence of population and ecologically unsustainable management practices that reduce soil organic matter and soil biota, mine plant nutrients and contribute to rainfall runoff and soil erosion (FAO 2011a; Montpellier Panel 2014).

Micro irrigation is used in some areas, such as in Burkina Faso where it is very successful. Supplemental irrigation can greatly enhance productivity and incomes in sub-zones where water is, at times, a constraint such as during the short drought between bimodal rains, or to permit a second cool season crop at the end of the main monomodal season. Rural energy (diesel cost) is often too expensive for pumping tube wells if they are not shallow.

Land use competition is evident in the inland valleys, which are important for both local and watershed water quality and supply. The water quality need competes with intensification of agriculture. In many inland valleys, dams have been built to hold water for irrigation schemes downstream.

There is a small amount of agroforestry in the farming system. The most prominent is the extensive culture of shea trees in crop fields and fallow lands. Teak as a homestead ‘tree bank’ has been effective in Benin in providing income at times of emergency and celebrations. Agroforestry and aquaculture have largely untapped potential in the zone.

There is some evidence that excess rainfall over evapotranspiration during the humid period in the growing season has decreased. In general, the farming system is not well adapted to climate change, neither is it geared to mobilizing and delivering key ecosystem services such as clean water, carbon sequestration, erosion control, biological nitrogen fixation and biological pest control. Crop and soil management practices that increase soil organic matter and encourage rainfall infiltration, will improve adaptation to erratic and shorter rains.

**Energy**

Most smallholder farmers use hand cultivation, and the use of draught power (livestock) and mechanization is low. There are marked variations in fuel costs within the farming system, with some countries such as Niger having very low-cost petroleum products, while others such as Burkina Faso do not. There are prospects for increased mechanization given the medium size of farms, and especially in west Africa where the landscape is less hilly and countries have cheaper fuel. An increase in mechanization would increase production and free up time for household members to sell or value-add produce or seek off-farm income.

Fuel for cooking is sourced from wood collected on-farm or in forests (firewood, charcoal making), sorghum and maize stover and dung, and this has a negative impact on forests and crop residues/nutrient cycling. The current use of charcoal, especially the
large quantities moved to urban centres, is not sustainable. Since the early 2000s, many households have changed from wood to domestic fuel (e.g. kerosene, gas), and the use of domestic fuels is expected to increase as incomes rise and where petroleum products are cheaper. Home-level power for night lighting, televisions and phones is increasingly available in rural area by solar panels coupled to batteries. An increase in access to inexpensive kerosene and electricity would have a major positive impact on production, poverty and natural resources.

There is the potential to use cassava for future bioenergy (IFAD/FAO 2010). In Mozambique near Beira, cassava-based ethanol is produced to sell along with inexpensive ethanol stoves produced in South Africa. This could be a model for other energy-deprived countries.

**Human capital/knowledge sharing/gender**

In general, the services provided to producers are not adequate in quality and relevance, and not easily available to women producers, for example, access to land, finance, markets, education, extension and knowledge. As outlined earlier, education levels are low particularly for women, and women have less involvement in farming and farm business. These factors can act as severe constraints to improving social condition and sustainable intensification.

Many technologies developed in Africa through formal research systems, including for this farming system, were not adopted by farmers simply because, although they were compatible with the bio-physical environment, they were incompatible with the socioeconomic conditions under which farming families operated. This lack of success led to the popularization of the farming systems approach and farmer participatory approaches in the 1980s in which farmers played a more active role in the research process (Collinson 2000; Norman 2002; Kassam et al. 2017). Adoption of a more integrated, holistic approach with strategic alliances of key stakeholders underpins new initiatives and innovation platforms such as Humidtropics, a CGIAR Research Program led by the International Institute of Tropical Agriculture (IITA). Similarly, the ‘Grow Africa’ partnership, founded jointly in 2011 by the African Union (AU), the New Partnership for Africa’s Development (NEPAD) and the World Economic Forum, works to increase private sector investment in agriculture, and brings novel ideas and resources to address development needs for the zone. More recently, the Australian Centre for International Agriculture Research (ACIAR) has supported conservation agriculture-based sustainable intensification (CASI) that is implemented in a participatory and flexible fashion (as a bundle of options for adoption in a flexible sequence rather than a fixed package) to ensure a good fit with the different types and stages of development of each farming system.

Increasing membership of farmer groups in this farming system indicates that information exchange is occurring between farmers, at least in some regions. There are some positive examples of community and group action, such as the Tanghin Kossodo Women’s cooperative where information exchanged through publications, training courses and study tours, as well as group support through a community of practitioners, has led to significant improvement in production and livelihoods through adoption of CA (Box 7.2).

Understanding and knowledge about ecological sustainability and sustainable production intensification of the farming system has improved considerably since the 1990s, through scientific research and farmer practice. However, integration and dissemination of this knowledge into practical farming has faced several barriers including intellectual,
social, lack of equipment and machinery, lack of development investment, and inadequate national policy and institutional support to farmers and service providers.

Introduction of television in rural areas has created awareness of alternative livelihoods and expanded expectations of youth who consequently want more for themselves and their own children. More recently mobile phones have improved information access, sharing and awareness of new opportunities and markets. These provide drivers for households to move to a future beyond subsistence living.

**Box 7.2 Crop-livestock integration and village enterprises**

The Tanghin Kossodo Women’s Farmer Cooperative Group in the Oubritenga Province, Burkina Faso, participated in a large, pilot scale programme (2,000 farmers in 30 sites) to enhance crop-livestock integration using CA. Major activities included silage and livestock production, specifically traditional chicken production, small ruminant management and cattle fattening. Through participating in the project, women farmers’ achievements included that:

- animals are now fed with locally produced silage and salt-lick supplement
- ewes maintain milk production throughout the year and Azaouak cows produce 10 litres of milk each day throughout the year
- the Cattle Fattening Action Group of the women’s cooperative received contracts from entrepreneurs in Ghana to supply fattened cattle
- farmers now undertake continuous silage production for sale, generating extra income for purchasing further livestock and for educating their children
- living standards and community life have significantly improved in the Oubritenga locality, including additional financial resources to expand their agricultural production businesses.

Source: FAO (2009).

**Science and technology**

A number of technology developments have helped increase crop and livestock production and commercialization in the farming system. A good example is cotton, which was promoted through the provision of inputs such as new varieties, fertilizers, insecticides, herbicides, animal traction equipment, farmer groups’ activities and extension support.

Other well-known examples are early-maturing, drought-resistant maize, dual purpose cowpea, tropical soybean, biological control of cassava mealy bug, improved rice varieties for irrigated production in Mali (see IITA and AfricaRice), and more recently CA practices using no-till, maintenance of soil cover, and crop diversification through rotations, crop associations and cover crops including dual purpose cowpea, mucuna and *Brachiaria* (FAO 2009).

The adoption of animal traction-based weed management in some areas permits farm families, traditionally limited by the area that they can weed and prepare for planting, to
expand the area cultivated. However, FAO, African Conservation Tillage (ACT) and others (Kassam et al. 2017; Sims et al. 2012) have reported that lack of knowledge on crop-input management and of new equipment such as no-till direct-seeders continue to be major constraints. Other constraints include lack of access to suitable genetic material for vegetables, oilseeds, legumes, forage and tree species, and inadequate storage facilities for some crops. Where adopted, improved farming practices have led to improvements in productivity and livelihoods (refer to System and subsystem performance section).

Markets and trade

The farming system has, for some time, been considered as one of the future bread baskets of Africa and has, historically, also been an important source of export earnings (Kassam and Kowal 1973; Kassam et al. 2017). Some key trends in markets in this farming system are shown below (in order of importance):

- Infrastructure and local roads have developed tremendously in the 2010s – and to some degree secondary roads.
- There has been a concurrent explosion of transportation resources (e.g. buses) allowing people to move, and increasing societal connection and purchasing power (smallholders have some access to utilities and trucks to move produce).
- Border handling and processing has been streamlined, resulting in less cost (including bribes) and time for supply chains.
- Continued improvement in infrastructure is expected.
- Africa-wide, there has been an improvement in information communication technology (ICT), increasing functional market access (see earlier).
- Because of the lower population density in this farming system and greater potential to produce surpluses, there is potential for greater market development and access.

Increasing population, rapid urbanization, higher incomes and changes in lifestyle are increasing the effective demand for agricultural products (Tiffen 2004). Diets of urban and non-agricultural rural consumers are diversifying away from the traditional food staples towards the incorporation of less coarse cereals – particularly rice and maize – as well as fruits and vegetables, new oilseeds such as soybean, and livestock products (poultry, dairy and meat).

There is substantial demand for meat in west Africa because of extensive urbanization. Consequently the demand for animal feed from cereals and soybean is expected to increase. The cost of nitrogen fertilizer plays a key role in feedstocks. Cassava, due to its lower requirement for nitrogen fertilizer, will likely replace some maize in the feed mills (Phillips et al. 2004). Cassava chips can be milled into a powder that can be mixed with other ingredients – such as soybean meal or other protein sources – to make a nutritious animal feed that is commonly supplemented with vitamins and minerals. Soybean protein, whose nitrogen comes from biological fixation, is likely to increasingly replace the protein from maize in feed systems.

There is intra-regional (inter-farming system) trade between countries, such as livestock trade between the cereal-root (e.g. Ghana) and agropastoral farming system, and crops between humid farming systems and Burkina Faso/Mali. The retail supermarket trade is evolving in many parts of Africa, and this is expanding market opportunities for high-value horticulture products, especially under irrigation in the cool season.
However, the effect of supermarkets is less in this farming system, which is less urbanized than others, with the major fruit and vegetable growing areas in west Africa outside the farming system.

In subsystem 1, groundnut, cotton and livestock used to constitute the bulk of cash income for farmers and service providers, but since the late 2000s the main cereals, pulses, oilseed, and root and tuber crops are increasingly serving as additional cash crops for the domestic market.

The market demand for cassava is also expanding somewhat (IFAD/FAO 2010; Truman et al. 2004), both for livestock feed (see earlier) and other uses. High quality cassava flour produced in Ghana and Nigeria can be used as a partial alternative to wheat flour and other starchy breads and confectionary.

Leaves from irrigated vegetable crops, including sweet potato and cassava, contain high percentages of protein and are a valuable source of iron, calcium, and vitamins A and C. Where irrigation is possible, vegetables provide great potential profit, especially for farmers located close to urban areas.

Despite improving infrastructure and roads in the 2010s, the time and cost to transport root crops to market and the quality of the road system remain barriers (Table 7.1). For example, in Western Cameroon it is not uncommon to see food crops rotting by the roadside, which are scarce and expensive in Douala, 200 km away. In contrast, when the all-weather road from Kano to Zaria in northern Nigeria was completed in the early 1960s, it immediately stimulated a dramatic increase in the output of chewing cane and vegetables to meet existing effective demand, completely independent of any research or extension activities.

The transport problem is acute in the case of cassava. Although it does not have a specific harvesting period, it has a very short shelf-life after it is harvested. Thus, rural producers and markets have to consider the whole supply chain, including transport infrastructure. Household profitability can improve where transport is better, or there are opportunities for commercial supply or local value-adding.

The farming system is on the cusp of an operational change to generate value-added products increasingly demanded by rural and urban populations and industry, both for domestic and/or international markets. The growing markets for protein concentrates and vegetable oils, coupled with the need for a rotation crop that enhances cereal crop productivity, make the expansion of soybean cropping very logical. The inclusion of cassava in feed formulations is providing market price stabilization and income opportunities from this food security crop. New yellow-fleshed sweet potatoes too have both food and feed markets.

African farming systems have attracted considerable international investment and large-scale land acquisition has become significant (Cotula 2011; HLPE 2011; Schoneveld 2011) with African land representing up to 60 per cent of the estimated 80 million ha of land acquisition globally (Bruntrup 2011). In relation to the cereal-root crop mixed farming system, the countries that have attracted most investors include Nigeria and Ghana, with a large number of other countries involved to a lesser extent. Although such investments can provide much needed capital for Africa’s agricultural development, there are socioeconomic and environmental risks such as accelerating forced migration to towns and cities, land degradation and disruption of ecosystem services (Bruntrup 2011), especially where governance structures are not strong. In some countries (e.g. Ghana) these land investments have clashed with existing farmers. Moreover, since most of the land is
leased to investors for renewable periods of 25–99 years, this may constitute long-term alienation of vital livelihood resources. A related concern is that huge amounts of hardwood trees are being extracted without reforestation, including in the cereal-root crop mixed farming system.

**Policies and institutions**

The actions and policies of both African and foreign governments in the recent past have led to many social, environmental and human problems in African nations, including indebtedness, inflated exchange rates and undue dependence on exports in ways which unsuccessfully continue colonial economic relationships.

Policies and practices which have had positive impacts on the farming system include Nigeria’s disincentives (tariffs) for importation of feedstocks, which ensures competitive markets for locally grown maize and soybean. Implementation of appropriate polices can further stimulate domestic food production and investment in rural infrastructure. Kofi Annan noted: “Investing in infrastructure will certainly be expensive. But at least some of the costs of filling Africa’s massive infrastructure financing gap could be covered if the runaway plunder of Africa’s natural resources is brought to a stop” (Kofi Annan in Africa Progress Panel 2014).

In the years up to 2015, there has been some investment in markets and roads but not irrigation (there is potential for future development of all of these). There is declining government investment in technology, farmer education and extension, as in most of Africa. Investment is declining rapidly in extension, and significantly in research.

Public and private sector institutions also have an important impact on the farming system. Three crops that stand out in terms of private sector involvement are: cotton in farming subsystem 1, and maize and soybean in both farming subsystems 1 and 2. Private-public sector partnerships could also bring about sustainable livestock intensification in the zone, perhaps looking to recent experiences in analogous zones in Brazil.

**System and subsystem performance**

In general, crop yields in the farming system are slowly increasing – rapidly for cowpea and maize, slowly for sorghum, and not increasing for cassava and root crops. The capacity of the farming system to increase production with appropriate management has been demonstrated during the adoption of cotton, soybean and early maturing maize with associated changes in practices (Figure 7.5).

Although poorer households in subsystem 1 grow cotton with no or few inputs, most cotton farmers in Francophone west Africa grow cotton as part of regulated production schemes with moderate levels of inputs. The liberalization and globalization of the cotton trade calls for further improvements in the competitiveness of cotton production, by reducing the costs of production and raising factor-productivities and yields.

In the case of maize, west Africa achieved the fastest rate of production growth in Africa, with annual increases of 4.5 per cent between 1975 and 1999 (Byerlee and Eicher 1997), with much of this expansion occurring in subsystem 1 where rainfall is relatively reliable, which reduced the risk of investing in inputs such as fertilizer. The price collapse of 2000 has largely recovered and production is growing at nearly 7 per cent in west Africa (Coulibaly 2014).
There is good agroecological potential for improving production, but to do this sustainably will require adoption of ecologically sustainable production systems and practices, especially with respect to soil health and achieving more output from fewer inputs. The main constraint to increasing livestock productivity and output is the lack of adequate supplies of good quality livestock feed in the dry season produced at a competitive cost without jeopardizing household food security. Destocking is not popular, since livestock is considered a capital stock where the number of heads is more important than actual production. In terms of crops, simply applying intensive mechanical tillage and external purchased inputs may not achieve the desired long-term gains, particularly if soils require rehabilitation and/or close nutrition management for integrated farming.

**Strategic priorities for the system**

**Population, hunger and poverty**

Africa’s population growth rates are already among the highest in the world and projections are for a four-fold increase by 2050. Consequently, the key priorities to address population, hunger and poverty are culturally sensitive policies to encourage birth control, alongside education on family planning, and programmes on better agriculture and food
systems. For the latter, more sustainable and integrated production systems, opportunities for intensification and value-addition, better distribution of produce between localities, and jobs outside farming to supplement household income, will all help improve household resilience, food availability and access.

**Natural resources and climate**

For small-scale farmers in subsystem 1, improved water management together with drip- and micro-irrigation can greatly enhance overall production, particularly during the dry season. This allows vegetable and dairy production resulting in improved diets and farm income. This potentially also applies to medium- and large-scale farming in higher fertility areas in subsystem 1. In larger-scale farms, investment in the use of central pivot, overhead sprinkler systems (common in commercial farms in analogous agroecologies in Latin America), may make sense when coupled with CA approaches and integrated crop and livestock systems. In locations with ample shallow groundwater and where energy is modestly priced, tube wells with efficient pumps, including axial flow pumps to move surface water to the fields could assist sustainable intensification of production systems. This approach is gaining traction in the Indo-Gangetic Plains in Eastern India (SCISA 2015) and could be tried in selected sites of the cereal-root crop mixed farming system in Africa. Water ponds with axial flow pumps for supplemental irrigation are gaining popularity in Central America, but are not commonly seen in this farming system in Africa.

The cereal-root crop mixed farming system has many climatic and edaphic similarities to the ‘Cerrados’ of Brazil, where agriculture has flourished since the late 1970s. In that region, CA, appropriate mechanization and farmer cooperatives have achieved significant improvements.

In the cereal-root crop mixed farming system, rehabilitating degraded soils, and better crop, soil and livestock management are critical to optimize biomass production to better meet the diverse demands for food, feed, firewood and fibre. This will require enhancing soil organic matter and soil health, including fixing nitrogen biologically. Fortunately, soils of African savannas are less acidic than most Cerrados soils. Pilot schemes evaluating no–till CA systems in the farming system in Ghana, Burkina Faso, Cameroon (FAO 2009; Lahmar et al. 2012) and elsewhere in Africa (Marongwe et al. 2011; Owena et al. 2011; Thierfelder et al. 2013; World Bank 2012) have shown that transformations are possible.

The farming system also needs to become more climate-smart, that is, adapt to climate change through biological soil health management, moisture capture and retention, and root system development that can support stronger resilient plants. Appropriate mechanization can facilitate adoption of these practices, by using CA principles, specific no–till direct seeding equipment, and precision farming technologies which reduce the use of inputs and the danger of soil compaction. Such systems can also mitigate climate change by sequestering soil carbon, thereby reducing emissions of greenhouse gases from the soil.

In the Brazilian Cerrados, organized community cooperatives have assisted with farmer learning and found solutions for grain handling. In the African farming system, often middlemen traders buy farm-gate grains at low prices. Family-farmers, with few options, are frequently vulnerable to such exploitation. Farmer cooperatives and centralized drying and grain storage strategies could improve farm returns, but these are constrained by the economics of hauling and inadequacies of rural roads. Perhaps public–private sector partnerships need to be found in each African country where this farming system is important.
Energy

Policies and markets that support increased access by rural householders to non-biomass energy (e.g. small-scale energy sources based on solar and batteries), electricity, petroleum fuel or renewable sources for domestic uses, and increased use of mechanized farming are required. Grain drying can be solar assisted but other power sources are required for rainy days. Power for pumping supplemental irrigation water is a must for reliable sustainable intensification. Cassava is being considered for bioenergy, especially in Ghana (IFAD/FAO 2010).

Human capital and information

The need to rehabilitate soil and reduce land degradation has implications for the extension and innovation system, for training of extension agents and farmers, and for management of crop–livestock integration at farm, community and watershed scales. Expanding farmer learning in soil health and sustainable agroecosystem management are ‘musts’ for governments concerned with food security, sustainable intensification and rural livelihoods.

However successful introduction is challenging, given that CA is knowledge and management intensive and requires change to the whole farming approach. Simple demonstrations, without direct farmer involvement in learning and discovery, will not be adequate. A phased approach tailored to the different circumstances and adoption capacities of farmers is more likely to be widely accepted and adopted. Empowering farmers through participatory techniques and fostering strong linkages between farmers, extension and researchers will be important in initiating and nurturing adoption. Delivery methods can build on the membership of farmer groups outlined earlier. Well-run Farmer Field Schools, such as those assisting adoption on IPM in Francophone west Africa, merit serious consideration for the introduction of CA systems.

Investment in trained ‘service providers’ who can contract direct seeding (preferably into no-till soils) and apply appropriate inputs, may be the best way to support appropriate mechanization. The service providers should be trained in CA and own the equipment for contract sowing (no-till direct seeding), as it is not feasible for most smallholder farm families to own and maintain the equipment required. Such ‘revolutions’ are underway in smallholder-based agriculture in eastern India. The agricultural machinery industry can also train some keen farmers to become service providers and trainers of trainers.

Broad adaptation and adoption of system approaches, including no-till CA, will depend on long-term investment in knowledge transfer. One advantage for Africa and the cereal-root crop mixed farming system, is that most farmers have experience in both cattle management and crop production. The diverse providers of information need to self-organize networks and be involved in broad programmes to adapt the science and technology for farmer adoption. Such multi-stakeholder innovation networks can include international agencies, multi-donor programmes, NGOs, national government staff, academic institutions, commercial organizations and agribusiness with their diverse points of view. Recent commitments by Brazil through EMBRAPA and other institutions, along with private sector involvement, could help jump-start sustainable intensification in the African cereal-root crop mixed farming system.

There is also a need to improve youth and adult education levels in the rural population, including women, to improve the opportunities for future employment and food security (Figure 7.6). As well as integrated farming, there is a particular need to increase capacity in value-adding, market trade and small business operation.
Another key need is for governments to support agricultural research and extension through initial training of professionals, and subsequent long-term resources, including adequate salaries and operational costs to enable them to work with farmer organizations on farmers’ fields. The current practice of expecting externally funded projects to provide the bulk of operational capital is not reasonable or sustainable. Closure of externally funded projects, even after promising short-term benefit, results in immediate collapse of national capacity to support farmers and a total disruption of work that requires continuity to bear fruit.

**Science and technology**

Some key research and development needs for this farming system include:

- striga control and management, including effective implementation and enforcement of existing policies
- aflatoxin reduction – promotion by governments of new technologies under the banner ‘Aflasafe’ that greatly reduce the incidence of toxins; farmers who produce toxin-free grain should be given meaningful financial incentives
• 60 day cowpeas and tropical soybean (based on research by IITA adoption has spread fairly fast) and other legumes to support diversification
• locally specific adaptation of CA practices including appropriate mechanization
• improving livestock integration including with crops, fodder production, rotation of pastures to break cropping, crop disease management, soil restoration and use of crops to fatten livestock
• extension and research that builds on the existing research on soil fertility and land management, livestock integration, feed, fodder and disease in this farming system, especially north of the trypanosomiasis zone
• storage, processing and marketing of root and tuber products, including for livestock feed
• short fallow management to clarify best-bet options for increasing total biomass production without decreasing the income flow to the farm family
• integrating tube wells and/or ponds to provide supplemental irrigation to extend the season and for winter vegetables.

Governments must provide meaningful and uninterrupted national plant breeding programmes to select and distribute crop genotypes and practices that are better-adapted to the actual climate, evolving farming systems, climate shocks and climate change. This should include crops not handled by private sector breeding programmes, for example cassava, sweet potato and Yam improvement.

Publicly funded research should also address the increased risk of soil degradation in the humid and sub-humid savannahs, which will require long-term research on sustainable soil, agroecosystem health, agroecological system approaches and appropriate practices. Greater adoption of CA will require locally specific adaptations along with extension to train farmers in the necessary knowledge and management expertise (Kassam et al. 2017).

Existing efforts to encourage smallholder adoption of mechanization must be expanded, including the use of no-till direct seeders, herbicide sprayers and two-wheel tractors. In India and Bangladesh, two wheel single-axle tractors coupled to locally built trailers are helping to reduce the drudgery of crop and input hauling. Relatively small no-till planters, coupled to two-wheel tractors, have also become popular. In the cereal-root crop mixed system, individual smallholder farmers are not likely to own such equipment and there are agribusiness opportunities for service providers to contract plant (preferably no-till) and use two-wheel tractors to unlock constraints for farmers. Reaper cutter-bars, coupled to the same two-wheel tractor-based equipment, can also be used for cutting hay crops for livestock feed. Where this innovation is available, managed pastures could be revisited as a crop rotation option. Soil health of the soils would benefit greatly from mixed pastures in the rotation. Mechanization research for the needs of smallholders in Africa is sorely needed and should be prioritized by the CGIAR and NARS in collaboration with agencies such as FAO, NGOs and the business sector.

The farming system has a diverse range of pests, given the range of crops that are grown. Insect pests are exceptionally difficult for cowpeas, which originate in Africa. Soybean was until recently relatively disease and pest free in Africa, but infection with Asian soybean rust has made the selection of tolerant varieties, and in some cases use of fungicides, necessary. The parasitic weeds striga in maize and alectra in groundnuts are increasingly problematic and will continue to be constraints if soil health (mostly soil organic matter) is not improved. Cassava virus problems continue to be a challenge. Cassava mosaic virus has been largely contained, but cassava brown streak (CBS) has since
The cereal-root crop mixed farming system

The cereal-root crop mixed farming system

the late 2000s been causing major losses in eastern and southern Africa. If and when CBS reaches west Africa, the implications will be dire unless better management is identified. The biological control of cassava mealy bug by introduction of predators from Latin America remains a major success story of IPM in Africa.

The importance of integration has been explained in previous sections. There are a variety of integrated strategic interventions which warrant attention in this farming system. The System of Rice Intensification (SRI), originally developed in Madagascar in the 1980s, offers an agroecological approach that is more productive than conventional flooded rice and requires less input of seeds, water, nutrients and pesticides. Since the early 2000s, SRI has spread and shown benefits in the farming system in Gambia, Sierra Leone, Mali, Burkina Faso and Cameroon, as well as elsewhere in Africa (Kassam et al. 2011; Uphoff et al. 2011). Similarly, successes in raising productivity have been reported for NERICA (New Rice for Africa, developed by AfricaRice) rice in the tillage-based upland cropping systems, for example in Guinea and Burkina Faso.

IPM promotes the use of natural enemies to control pests, so that the use of pesticides is kept to a minimum. In subsystem 2, the IPM approach is being applied to tillage-based farming such as cotton, and to integration of soybean into the cropping system. In subsystem 1, it has also had considerable success, for example in Burkina Faso and Mali (Settle et al. 2013) through integrated crop-nutrient-pest management in tillage-based smallholder systems, and has reduced pesticide use in cotton, rice and diverse vegetable crops.

Another key integrated farming system solution, introduced earlier in the chapter, is CA, which is based on three principles: (i) permanently minimize or avoid mechanical soil disturbance (no-till seeding and weeding); (ii) maintain a continuous soil cover of organic mulch with crop residues and cover crops; and (iii) grow diverse plant species in cropping systems, all contributing to enhancing soil quality, system resilience, ecosystem services and sustainability. In other parts of the world with similar characteristics, CA has proven over time to increase soil organic matter levels, health and water holding capacity. This results in increased biomass production, resilience against adverse climatic conditions, improved livestock production and better integration of crop and livestock production in a controlled and managed way (Junior et al. 2012; Landers 2007). In Africa since 2008 more than one million hectares have been brought under CA (Kassam et al. 2013, 2015, 2017, 2018). In this farming system, the major attractions of CA are its potential labour-saving and increased efficiency in use of inputs. By integrating the CA technologies into maize, cotton, sorghum and cassava, system performance can be further improved and made sustainable.

CA should be relatively easy to adapt and adopt in the cereal-root mixed crop farming system, due to adequate rainfall, reasonable soils (if managed), and the suitability of the farming system to diversification, along with the larger fields relative to other farming systems. Where farmers have access to animal traction or tractors, rippers are used to open the planting lines for manual seeding, or no-till direct seeding equipment drawn by animals or tractors. Such systems have been employed successfully in mixed cereal cropping systems in the region and could also be used for root crops such as cassava (Howeler et al. 2013) and sweet potato.

Another opportunity to strengthen integration lies with agroforestry, whereby economically valuable trees can be integrated into both subsystems. The shea tree has been naturally regenerated and cultured across tens of millions of hectares in the farming system for many generations. Harvesting, processing and sale of shea nuts or butter is a major source of women’s income. Demand for shea has been increasing rapidly, creating more
competitive markets and accelerated interest in the development of the industry. In areas where land is less of a constraint, farm families could put some land into fast growing trees such as eucalyptus, teak and rose wood. Economic harvest can take up to 10 to 15 years but in the long term farmers can attain financial security if fire can be controlled and farmers have long-term ownership of the land resource. Smallholder teak, for example, has been planted in several countries (e.g. Benin, Ghana). Ghana has an active agroforestry programme for the savannahs, with the implementation of incentives and support nurseries enabling farmers to plant and maintain trees as part of their farming system.

Leguminous trees and perennial shrubs can also be intercropped with crops. For example, cassava can be planted in alleyways between rows of deep-rooting and fast-growing leguminous trees, such as *Leucaena leucocephala* and *Gliricidia sepium*. In drier areas, deep-rooted trees compete less for water and nutrients than other intercrops. The foliage is cut back regularly and the prunings are either incorporated into the soil of the alleys, or in a zero-till system, applied as mulch before the cassava is planted. Leaf cuttings from forage legumes such as *Flemingia macrophylla* have a particularly positive effect on root yield of cassava (Howeler et al. 2013). Also successful are leguminous trees such as *Faidherbia albida*, with its loss of foliage during the rainy season. This means it does not shade crops, but instead provides nitrogen for the field crops through decomposition of its leaves (Evergreen Agriculture or ‘CA with trees’; Garrity et al. 2010; Kassam et al. 2017).

The expansion of peri-urban poultry throughout the farming system and beyond, depends on feedstocks. There are opportunities for expansion of improved (planted) pastures as a rotation option with crops used for intensification of cattle for meat and dairy. Recently, efforts in Zambia have borrowed from models in the Brazilian Cerrados which use intensely managed pastures, often in rotation within CA’s no-till annual cropping systems. There are many factors that will govern such transformations, such as access to land, seed, knowledge of the system and availability of no-till planters.

Along with supplemental irrigation, investment in grain drying and storage could also add important opportunities for intensification in production areas in subsystem 2 where the bimodal rainfall creates storage challenges.

**Markets and trade**

As outlined earlier, there are emerging markets for cereal, root and tuber and other crops in this farming system, in response to increasing population, urbanization and changing demands. This is stimulating domestic food production, increased value-adding and sale of feed for livestock intensification.

Market policies need to ensure that conditions enable all stakeholders to make a living. This includes creating infrastructure to reduce the costs of bringing inputs to farms, facilitate marketing of farm produce and allow transition from subsistence to income-generating farming and commercialized agriculture.

An essential problem is to change the risk environment so that smallholder farmers have the knowledge and decision processes to more proactively manage and engage with risk. This helps markets and trade to respond rather than being the result of smallholder farmers’ risk-averse livelihood strategies based on previous experiences (Holden and Quiggin 2015). Value chain analysis can assess ways of improving business performance, product development, sustainability and greening the chain, opportunities for cluster developments, economic rents (how much money can be extracted from each stage of development) and governance structures.
Institutions and policies

Governments and public and private institutions must help establish and maintain an enabling environment to facilitate investment and agribusiness while protecting the natural resource base, environment and food quality and safety. Policy choices must both establish and maintain supporting infrastructure, research and services. Different public institutions need to be involved, including education, training, legal and financial. A key need is adaptation of local bylaws, including farmer rights to land and their access to crop residue/potential mulch on their land.

Further development of physical infrastructure (e.g. roads, bridges, power supplies, market structures) and communication infrastructure (e.g. phone systems, standardization of measurements, price dissemination) is required to facilitate input and output delivery systems and marketing. Electrification, well-maintained roads, finance, schooling and unbiased information are examples of domains where government inputs are essential. New solar-based rural electrical systems with contractual renting of power seem promising, but public and private sector investment is not yet adequate.

Government policy and implementation strategies are also needed (Kassam et al. 2017, et al. 2018) to:

- encourage access, via the private sector, to no-till mechanization equipment that is appropriate for small family farms in the farming system
- provide supportive services (roads, electrification) and research to facilitate uptake and spread of CA (Kassam et al. 2013, 2015) through new area-wide development programmes in economic/production corridors
- encourage small enterprises to provide farmers with seeds for cover crops and disease-free planting materials for major crops
- work with cooperatives to create credit based on farm-stored grain that can be held until sale prices are attractive to the farmer
- link diverse partners’ goals and prioritize and facilitate win-win investments; needs of family farmers should be prioritized so that they can evolve to become more commercialized producers
- develop a supportive, enabling environment for the private sector to develop and operate the marketing functions.

While governments have primary responsibility for providing the infrastructure, experience in west Africa has shown that the delivery systems are best operated by the private sector (e.g. credit programmes, transportation, production and distribution of inputs, processing and marketing of products) and are more efficient if they are operated with as free a market as possible (Figure 7.7). With the increased commercialization of agriculture these can become very important employment generators. The private sector also has a significant role in equipment development (e.g. design and sales of no-till seeders). Similarly, there are opportunities for useful partnerships between the public and private sector to supply appropriate equipment and machinery to smallholder farmers.

A key input need is supply of seeds – in particular oilseeds and selected pasture, forage, tree and legume seed (including cover crops) suited to the dry sub-humid zone. There could be opportunities for specialized seed businesses involving smallholders, and especially women, with appropriate training.

Cooperation is required with other nations, international agencies and the private sector, in areas such as investment, trade, education, training, research and management.
of common interests. Some firms have made substantial long-term contributions to the development of nations and regions. Partnerships between African governments and private investment, including foreign, may help bring positive benefits to African agriculture and food systems, but governments must make sure that their countries share the benefits.

From a policy viewpoint countries should proceed very cautiously with large-scale land acquisitions. Balanced win-win solutions are needed so that the watersheds that feed the agroecologies are not destroyed and the host country shares the benefits. Under special conditions, judicious land acquisition could bring innovative, sustainable intensification of production systems. At the very least, protocols should be agreed to ensure such land is used in a sustainable manner and that the livelihoods and access to resources of local farmers are not jeopardized. Finally, large-scale land acquisitions should be integrated into the host country’s broader rural development policies and strategies (Bruntrup 2011).

Relative importance of the five household pathways

In this farming system, intensification offers the greatest potential for farm households’ escape from poverty and also for increased farm income for the less poor households. There is less opportunity for the poor to increase farm size, diversify crop and livestock production (the system is traditionally diversified), increase off-farm income or exit from

Figure 7.7 Private sector cassava processing for fermentation of ethanol, a fuel for cooking stoves that do not use wood.
Source: Judee Fisher.
agriculture (Table 7.3). Exit from agriculture is very dependent on alternative income sources arising from migration to urban areas. The exit strategy would become increasingly important: where farm sizes become smaller due to increased population density; where biomass production potential is lower (e.g. in drier areas); and as economies grow and become more diversified, offering wage employment and business opportunities for rural youth. One concern, which could force the involuntary exit of people from agriculture, could be allowing inappropriate large-scale land acquisitions.

Overall, it would seem that the prospects for agricultural growth and development are medium-high, and the prospects for poverty alleviation are medium. Growth through intensification is feasible because of the favourable agroecology and improvements in market access. Off-farm income has become more important since 2000, whereas for the poor the opportunities for expanding farm size have reduced (although this remains a pathway for the somewhat better-off households). Increasing numbers of poor farm households are expected to leave this farming system, especially for urban areas. For overall farming system development for poverty reduction or economic growth, the primary focus of policy and research should lie with intensification.

### System conclusions

The cereal-root crop mixed farming system has, for some time, been considered one of the future bread baskets of Africa. Increased food production will require focused investments by governments and by the private sector. The potential for household poverty reduction appears to be good because of the promising agricultural growth prospects in the farming system (World Bank 2009).

Global effective demand for commodities such as cotton, groundnuts, soybeans, cowpeas, maize, cassava and yams as well as livestock have been driving agricultural intensification and diversification and will continue to do so in the future (IAC 2004; World Bank 2009). Opportunities to commercialize the farming sector will become even greater as economies become stronger, per capita income rises and the non-agriculture sectors increase effective demand for agricultural products. There are significant opportunities for intensification, given the adequate rainfall and soils (if well managed) and more choices in crop and livestock production relative to the farming systems to the north and south.

The huge potential for intensification of medium-scale agriculture (and larger food systems) could occur quite quickly given the larger average farm size relative to some other high-potential farming systems in Africa. Development of land markets and land tenure arrangements that allow farm consolidation would support this. Medium-scale farming is

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<tr>
<td>% of total ag pop</td>
<td>–</td>
<td>55</td>
<td>45</td>
<td>100</td>
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<tr>
<td>Intensification</td>
<td>3.5</td>
<td>3</td>
<td>4</td>
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<td>Diversification</td>
<td>2</td>
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<td>1</td>
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<tr>
<td>Increased farm size</td>
<td>3</td>
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<td>Off-farm income</td>
<td>1</td>
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<td>Exit from agriculture</td>
<td>0.5</td>
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Sources: See Chapter 1, ‘Farm household decisions and strategies’ and Chapter 2, ‘Household strategies’.
often associated with faster adoption of new technologies and opportunities for private investment in seed inputs, purchasing, grain drying and storage facilities, and feed mills.

However, the continuation of current conventional tillage farming is likely, in the near future, to lead to a major decline in productivity because of the associated soil degradation. Fundamental changes in farming are required to enable soil organic matter to increase and resilient ecosystem functions to be restored. This can be achieved by using crop production methods based on the ‘Save and Grow’ principles of CA and precision farming, as well as IPM and integrated crop, nutrient and water management (FAO 2011b).

Government’s role in enabling education, research and participatory extension, and rehabilitating degraded landscapes and ecosystem services, will become even more important in coming decades as greater pressures are put on the natural resource base. Some practices and innovations needed for sustainable intensification are knowledge intensive and require systems-appropriate management rather than reliance on purchased external inputs. For effective application of these innovations, farmers need participatory learning processes, trained facilitators and community organizers underpinned by effective strategies, implementation plans and funding. This calls for strong, publicly funded research and extension services.

Mechanization appropriate for smallholder farmers, supportive land policies (access and security) and efficient markets are also needed to improve the outlook for the farming system. Governments and the private sector can help enable these. Private sector dealers in appropriate mechanization need to be encouraged, alongside increased capacity, to ensure the correct use and maintenance of the equipment contracted out to smallholders.

Private sector investment is required in: science and technology (to match public input), communication resources, infrastructure (roads, electrification and other energy sources, grain storage), market information, transport, financial resources including credit, access to inputs, and emerging knowledge systems and other social services. Thus, an enabling environment for private agribusiness needs to be established, including government and private sector partnerships to establish infrastructure, services and markets. Novel approaches to holistic strategic planning are emerging in Africa, including economic corridor initiatives in zones with favourable agroecologies, for example in Ghana. The USAID-funded initiative of Feed the Futures is designed to harness such partnerships. New programmes such as ‘Grow Africa’ provide further opportunities for public-private investment in supporting infrastructure and institutions.

As the farming system evolves over the coming decades, far reaching changes will occur in farm size, number of farmers, farm mechanization, use of supplemental irrigation, grain drying and storage, and management of rural development and linkages between rural and urban economies. The technical and political challenges are reasonably well known. As African economies grow and diversify, the effective demand for food and other agricultural products will provide a basis for fostering sustainable intensification of agriculture. This must enhance food security and livelihoods, as well as rehabilitate degraded agroecosystems and provide ecosystem services for farmers, the community and society at large.

Notes
1 Inland valleys are the natural water drainage channels in the landscape, serving as source of domestic water as well as production environments for long-season crops such as banana and root and tuber crops in addition to rice and vegetables.
2 The tops (stems and leaves) of crop plants after the crop has been harvested.
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