CHAPTER

5

Intensive Cereal–Legume–Livestock Systems in West African Dry Savannas

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Contents

Abstract

The dry savannas of West Africa are undergoing rapid transformation of agricultural practices owing to the rapid human and livestock population growth, increase in agricultural intensification and accelerated climate change which has increased the incidence and severity of diseases, pests and drought. The major constraints to agricultural production in the savanna include poor soil fertility, pests and diseases of crops and livestock, parasitic weeds such as *Striga hermonthica*, drought, and competition between crops and livestock for resources, Inadequate policies, weak institutional mechanisms, and poor linkages among farmers, and researchers prevent adoption of improved agricultural technologies that can combat these constraints. The risk of continuous cultivation on these poor and fragile soils is huge. Integrating crop and livestock production offers ways to increase production while protecting the environment. Over the years, research and development institutions have generated several agricultural technologies to alleviate the majority of the production constraints in the West African savannas. However, most development organizations use traditional extension methods that result in poor adoption of the improved technologies. The integration of crop and livestock production is particularly desirable in intensively farmed and densely populated areas with access to urban markets. Proper integration of these practices will diversify smallholder income and increase food security. Integrated genetic and natural resource management provides the keys improved eco-efficiency. This includes integrating pesticide use with cultural practices such as modified planting date and disease control; rotating/intercropping cereals and legumes; use of pest resistant\tolerant cultivars to increase the effectiveness of pest control and reduce the need for pesticides; and improving soil fertility restoration/maintenance. Government and national institutions in West Africa are encouraged to scale-out these technologies to wider areas for increased benefit to farmers through the use of proven extension methods.

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Introduction

The lowland savannas of West Africa are characterized by elevation of less than 800 m, a growing period sufficient for most cereal and grain-legume crops, and a relatively high potential for livestock production. Agricultural production systems are intensifying across the region in response to increases in population pressure, demand, and opportunities for product marketing. In the dry savanna, defined as the area with a growing period of between 4 and 6 months, cereal and legume cropping systems are being intensified and traditional crops—sorghum [*Sorghum bicolor* (L.) Moench subsp. *Bicolor*], finger millet [*Eleusine coracana* (L.) Gaertn.], cowpea [*Vigna unguiculata* (L.) Walp.], and groundnut (*Arachis hypogea* L.)—are being replaced by new crops such as maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] (Sanginga et al., 2003). Throughout the Guinea and dry savannas of West Africa, farmers increasingly combine crop farming with livestock production (Tiffen, 2004). The integration of crop and livestock production is particularly noted in intensively farmed and densely populated areas with access to urban markets (Franke et al., 2010).

Alongside the increase in cropping intensity, livestock numbers are also increasing in response to an increased demand for meat, milk, and other products. Delgado et al. (2001) estimated that demand for animal products in sub-Saharan Africa would increase by more than 250% between 2001 and 2020, with much of the increase being in West Africa. Intensification of crop–livestock systems in the region has resulted in shorter fallows than in traditional farming systems, and fallow periods are becoming too short to restore soil fertility and reduce pest pressure. Consequently, cropping and grazing have expanded onto marginal lands, increasing competition between cropping and livestock production and increasing demand for crop residues as livestock feed.

Addressing Major Constraints to Agricultural Production in the Dry Savanna

The major constraints to agricultural production in the savanna include poor soil fertility (including low soil organic matter (SOM) content in intensified cropping systems), pests and diseases of crops and livestock, parasitic weeds such as *Striga hermonthica* (Delile) Benth. (purple witchweed), drought, and competition between crops and livestock for resources. Inadequate policies, weak institutional mechanisms, and poor linkages among farmers, development agencies, and researchers prevent adoption of improved agricultural technologies that can combat these constraints. Most development organizations use traditional extension methods that result in poor adoption of improved technologies.

Poor soil fertility

Crop production in the West African dry savanna is limited by the inherently low fertility of most of the soils. In the past, farmers depended on fallow periods to restore soil fertility, but current fallow periods are not long enough to replace exported nutrients (Bado et al., 2012). Stoorvogel et al. (1993) estimated annual nutrient loss from sub-Saharan African soils is at 22 kg N, 2.5 kg P, and 15 kg K/ha in 1982–84, and 26 kg N, 3 kg P, and 19 kg K/ha in 2000. This underscores the extent of nutrient mining and the need to mobilize strategies to conserve soil fertility.

SOM plays an important role in sustaining soil fertility by contributing to several soil properties, including cation exchange capacity, water-holding capacity, buffer capacity, and soil structure. Higher levels of SOM could also raise the efficiency with which mineral fertilizer is used by plants. However, SOM is very low in most savanna soils, averaging 6.8 g/kg (Jones, 1973), compared with a 20–100 g/kg for most soils (Bot and Benites, 2005). Increasing SOM contents is therefore considered a prerequisite for increased crop production in the savanna. This can be achieved by growing crop varieties that produce large amounts of above-ground biomass, incorporating residues in the soil where the crop was grown, concentrating plant residues on a limited cropped area, and corralling livestock on crop fields so that they deposit urine and manure on the cropland (Bationo and Mokwunye, 1991; Powell et al., 2004; Valbuena et al., 2012).

Nitrogen (N) is the most limiting nutrient in soil. In the savannas, considerable amounts of soil-available N are released with the onset of rains but its uptake by crops is insignificant due to the low N requirements of plants at early growth stages (Kamara et al., 2005). As a result much of this N is lost through leaching. Phosphorus (P) is the second most limiting nutrient in the savanna soils of West Africa, and in some areas, plant-available P may be as low as 2 mg P/kg (Bray 1) (equivalent to approximately 4 kg P/ha) (Kwari et al., 1999). Most of these savanna soils also contain large amounts of iron and aluminum oxides, which contribute to the removal of P from the soil solution. Because P is not a renewable resource, the soil P pools can be replenished only through external P inputs. In addition, the acidity that is generated through crop removal and leaching can lead to the loss of calcium (Ca), magnesium, and potassium (K), and toxic levels of soluble manganese and aluminum.

Although mineral fertilizers can be used to replace nutrient losses, socio-economic constraints such as high prices and lack of credit limit their use. Smallholder farmers commonly apply too little fertilizer, either because they cannot afford more or because fertilizers are not readily available. Moreover, most fertilizers applied contain N, P, and K, albeit in inadequate quantities. Applying these fertilizers initially increases yields, but this accelerates depletion of other soil nutrients such as sulfur, copper, and zinc, ultimately reducing response to NPK fertilizer and reducing crop productivity (Kwari et al., 2009). Thus, both mineral fertilizers and organic inputs are required to improve soil fertility (Vanlauwe et al., 2002; Powell et al., 2004).

Other problems include physical deterioration of soils, such as crusting (Oldeman, 1994), which reduces water infiltration, increases runoff, reduces oxygen diffusion to seedlings, inhibits plant growth, and reduces soil biological activity, and the breakdown of soil aggregates, which increases soil erosion. There is thus a great challenge to protect and manage land and soil resources to maintain their productivity and to contribute to food security.

Increased use of organic and inorganic fertilizers, together with diversification of cropping to include legumes are important tools in restoring or sustaining soil fertility of the intensifying cropping systems of the dry savannas of West Africa (Vanlauwe et al., 2001; Sanginga et al., 2003; Franke et al., 2004). These so-called "balanced nutrient management systems" can be further enhanced through the use of improved cultivars that are drought tolerant and use available nutrients efficiently, such as maize cultivars developed at the International Institute of Tropical Agriculture (IITA), Nigeria (Kamara et al., 2005). This approach has come to be known as integrated soil fertility management (ISFM). ISFM is not characterized by unique field practices, but is rather a fresh approach to combining available technologies in ways that preserve soil quality while promoting its productivity (Sanginga and Woomer, 2009).

Pests and diseases

Plants

Insect pests are a major constraint to legume production, particularly cowpea in the dry savannas of West Africa (ICIPE, 1980; Singh and Allen, 1980; Singh et al., 1990; Rusoke and Rubaihayo, 1994). Indeed, Jackai et al. (1985) assert that it is not feasible to grow cowpea commercially in the West African savanna without using insecticide. In a recent study, Kamara et al. (2007) reported that flower thrips [*Megalurothrips sjostedti* (Trybom)], the legume pod borer (*Maruca vitrata*) and a range of pod-feeding bugs were the major insect pests of cowpea in the dry savannas of West Africa. Thrips start to attack at flower initiation, causing flower bud abortion (Akingbohungbe, 1982). Pod borer larvae damage flower buds, flowers, green pods, and seeds (Singh and Jackai, 1985). Adults and nymphs of pod bugs remove sap from green pods, causing abnormal pod and seed formation (Singh and Jackai, 1985). High levels of insect resistance are not available in current cultivars (Oghiakhe et al., 1995), hence integrated insect pest management is key to successful cowpea production (Ajeigbe and Singh, 2006; Kamara et al., 2010).

The most important diseases of cowpea in the dry savannas of West Africa are bacterial blight (*Xanthomonas* sp.), leaf spot (*Septoria* spp.), and scab (*Sphaceloma* sp.) (Emechebe and Florini, 1997; Hampton et al., 1997).

In West Africa, groundnut yields are traditionally low, due to several constraints including pests and diseases. Aphids (*Aphis craccivora*) are a serious pest as well as a vector of virus diseases, such as the rosette, a major constraint to groundnut production, particularly in the dry regions. Groundnut rosette disease (GRD), early leaf spot (ELS), late leaf spot (LLS) and rust are the major biotic constraints responsible for low yield of groundnut in West Africa (Ntare et al., 2008). Groundnut rosette is one of the most important diseases that wiped out more than half of the groundnut cropped area in Nigeria in the mid 1970s. From 1992, ICRISAT and National partners in Nigeria embarked on a large hybridization program to develop early maturing rosette resistant varieties that would fit into the Sudano-Sahelina savanna zones of Nigeria. From this program, a total of 44 new varieties with resistance to groundnut rosette were tested (Mayeux et al., 2003). Three varieties SAMNUT 21, SAMNUT 22, and ICGV-IS 96894 (SAMNUT 23) were formally released in 2001 and ICIAR 19BT (SAMNUT 24) was released in 2011.

Infection by *Aspergillus flavus* on groundnut (and its products), is the main food safety concern. Aflatoxin contamination causes cancer to humans and animals and has thus adversely affected international trade in groundnuts in many producing countries (Ntare et al., 2008). Resistant cultivars provide the most appropriate means of control of diseases, especially for smallholder farmers. Therefore, development of rosette-and/or ELS resistant, high-yielding groundnut varieties with appropriate duration is important to enhance and stabilize productivity. Early planting and dense close spacing are effective cultural practices. Early planting allows plants to start flowering before aphids appear. Dense planting provides a barrier to aphids penetrating in from field edges, discourages population build-up of aphids and reduces incidence of "rosette" disease. Other diseases of groundnut include; bacterial wilt (*Ralstonia solanacearum*), and damping-off diseases (*Pythium spp*., *Rhizoctonia solani*). In some locations termites are serious field and storage pests. Species of *Microtermes* and *Odontotermes* are the most damaging, while *Macrotermes* cause occasional damage. The small-sized *Microtermes* spp., in particular, attack and invade growing groundnut plants through the roots and stem near ground level, hollowing them out and causing the plants to wilt and die with a consequent reduction in crop stand. Stored groundnuts are attacked by moths (*Ephestia cautella, Plodia interpunctella*, *Cadra cautella*), and beetles (*Caryedon serratus, Tribolium castaneum, Trogoderma granarium*). The larvae of moths and the grubs and adult beetles bore into and damage seeds. Moths cause extensive webbing. The bruchid beetle *Caryedon serratus* is the major pest of groundnut in pod shell in West Africa. A good postharvest pest management program based on good storage practices is very important.

Insect pests constitute an important factor limiting grain sorghum production in West Africa. Several species of insect pests attack sorghum at the different stages of its development. Several lepidopterous stem borer inflict considerable losses in sorghum. Intercropping cereals with legumes has shown to reduce stem borer attack and damage in sorghum (Amoako-Atta et al 1983; Ampong-Nyarko et al., 1994) and has been recommended as a component of integrated pest management for small-scale resource limited farmers. Insect pests attacking panicles of sorghum and millet are especially damaging as they affect crop development at a late stage and have direct harmful quantitative and qualitative effects on grain yields. At this late stage of crop development the main production inputs would have already been made, which maximizes economic losses and there is also little scope for the crop to compensate for damage done close to harvest. Sorghum midge (*Contarinia sorghicola*) is the most wide spread and damaging insect species attacking sorghum. It occurs almost everywhere that the crop is grown. Sharma (1993) reported that substantial progress has been made in utilizing resistance to midge. Millet head miner (*Heliocheilus albipunctella)* is the most important pest in West Africa. Nwanze and Sivakumar (1990) reported crop losses on farmers fields up to 41% with a mean of 20% based on field surveys in Burkina Faso, Niger and northern Nigeria. Other important insect pest include shoot fly and aphids.

Several fungi and viral diseases also attack sorghum and millet crops in West Africa. Grain mold caused by several fungal pathogens can reduce grain quality or destroy seeds. Stem rot and leaf diseases caused by an array of fungal and bacterial diseases cause spots or stripes on leaves which can result in death of the leaf (House, 1987). Downy mildew (DM) caused by an obligate parasite *Sclerospora graminicola* is quite widespread and economically the most important disease of pearl millet (*Pennisetum glaucum*) in India and several countries in Africa (Thakur, et al., 2008). Severely infected plants are generally stunted and do not produce ear heads. Resistant varieties and other cultural practices are the most important control measures under smallholder farming systems of West Africa.

The major insect pest problems on maize in the West African savannas are the stem borers, (*Busseola fusca* and *Sesemia calamistis*); and army worms (*Spodoptera exempta* and *Helicoverpa armigera*). The stem borer attack is usually more serious in late-maturing maize than the early cultivars. They cause two types of damage to the plants. First is mechanical damage due to consistent feeding in the stem, weakening it, and thus rendering the stems susceptible to lodging and withering (dead-heart). Secondly, stem borers may cause characteristic perforations or windows on leaves called 'fenestrations' seen when the sheath opens, exposing the perforations (Bosque-Peréz and Schulthess, 1988) This type of damage reduces the photosynthetic area of the leaves resulting in poor cereal yield, especially during high infestation.

In a survey for incidence and severity of diseases in both the northern and southern Guinea savannas of Nigeria, Adeoti (1992) reported the occurrence of common foliar diseases such as the rust induced by *Puccinia* spp, *Turcicum* blight, *Curvularia* leaf spot and *Maydis* blight. Other important maize diseases occurring in the savanna ecological zones include smut (*Ustilago maydis*), downy mildews, maize leaf fleck and maize streak.

Integrated pest management—integrating biological control, cultural practices such as modified planting date, disease- and pest-tolerant cultivars, and pesticides where necessary—can increase the effectiveness of pest control and reduce overuse of pesticides. Manipulation of planting date with a judicious use of insecticides has been found to be profitable (Kamara et al., 2010). Efforts are being made to develop biological control methods to control insect pests (e.g., Wajnberg et al., 2001; Neuenschwander et al., 2003; van Driesche et al., 2008). However, further efforts are needed to develop crop cultivars that are resistant to or tolerant of the major pests and diseases of the West African savannas in order to promote sustainable, eco-efficient agriculture in the region.

Animals

The major pests and diseases affecting livestock in the West African savanna region include anthrax, black leg, contagious bovine and caprine pleuropneumonias, dermatophilosis, ectoparasites, gastrointestinal parasites, heartwater, liverfluke, respiratory complexes, and trypanosomiasis (Perry et al., 2002). High prevalence of diseases and parasites causes high mortality in sheep and goats, especially in kids and lambs. Preweaning mortality of up to 40% has been recorded with kids and lambs in Nigeria, but levels may be higher under extensive systems (Ademosun, 1994). Parasites may aggravate other conditions, such as nutritional stress, and increase susceptibility to disease, especially in young animals.

Livestock health can be improved in smallholder systems by application of simple, low-cost, and well-proven techniques. These include control of pests, parasites, and diseases using traditional or modern veterinary medicines or husbandry practices (see, for example, Okoli et al., 2010), tolerant breeds of livestock, improved feeding, and hygienic housing and handling facilities. The improvements in productivity achieved by implementing such approaches can be dramatic. Van Vlaenderen (1985; 1989), for example, demonstrated increases in ewe productivity of nearly 300% (from 7.2 kg lamb/ewe per year to 28.7 kg lamb/ewe per year) through improved flock management, simple health control, mineral supplementation, and strategic supplementation at the end of the rainy season. However, encouraging widespread adoption of these improved husbandry practices will require investment in policies, markets, and extension services (McDermott et al., 2010).

Parasitic weeds

Parasitic flowering plants (*Striga* and *Alectra* spp.) pose a serious threat to cereal and legume production in the dry savannas. It is estimated that 40 million hectares of land are severely infested by *Striga* spp., while nearly 70 million hectares have moderate levels of infestation (Lagoke et al., 1991).

Striga hermonthica (Delile) Benth. (purple witchweed) is one of the most severe constraints to cereal production in the dry savannas of West Africa (Oswald and Ransom, 2004), attacking millet, sorghum, maize, and upland rice (*Oryza sativa* L.) (Kim et al., 1997; Showemimo et al., 2002). In northeast Nigeria, over 85% of fields planted to maize and sorghum were infested with purple witchweed (Dugje et al., 2006). Striga infestation can result in total loss of the crop (Lagoke et al., 1991; Oikeh et al., 1996) and may force farmers to abandon their cereal fields. The increasing incidence of striga has been attributed to poor soil fertility and structure, intensification of land use through continuous cultivation and an expansion of cereal production (Vogt et al., 1991; Rodenburg et al., 2005; van Ast et al., 2005).

Striga gesnerioides (Willd.) Vatke (cowpea witchweed) and *Alectra vogelii* (Benth.) (yellow witchweed) cause substantial yield reduction in cowpea in the dry savannas of sub-Saharan Africa (Emechebe et al., 1991). In a survey of 153 cowpea fields in six countries in West Africa, 40% were found to be infested with striga (Cardwell and Lane, 1995), while in northeast Nigeria, where cowpea is the important cash crop, Dugje et al. (2006) found 81% of cowpea fields surveyed to be infested with striga, leading to serious crop losses. Cowpea yield losses associated with cowpea witchweed has been reported to range between 83 to 100% (Emechebe et al., 1991; Cardwell and Lane, 1995). Both parasites are difficult to control because they produce large numbers of seeds and up to 75% of the crop damage is done before they emerge from the ground.

The abandonment of long-term fallows as a result of increasing cropping intensity has removed one of the key traditional practices used to control parasitic weeds. The primary approaches to management of parasitic weeds now available are the use of tolerant or resistant cultivars, and agronomic practices such as crop rotation.

Striga damage in cereal crops can be reduced by growing varieties of maize (*Zea mays*), sorghum (*Sorghum bicolor*), and pearl millet (*Pennisetum glaucum*) that are tolerant of or resistant to striga or by planting trap crops such as varieties of groundnut (*Arachis hypogaea*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*), and sesame (*Sesamum indicum*) that stimulate striga seed to germinate without providing a viable host (Carsky et al., 2000). Some studies have shown that applying N fertilizer reduces striga emergence and population and boosts cereal grain yield (Kim et al., 1997; Showemimo et al., 2002; Oswald and Ransom, 2004; Kamara et al., 2009). Applying N fertilizer may not be feasible as a stand-alone solution to managing purple witchweed in cereals because of the high cost of fertilizer, but the combined use of N fertilizer and striga-tolerant/resistant maize and sorghum varieties has shown promise in the West African savannas (Showemimio et al., 2002; Kamara et al., 2009). In addition, farmers have developed a range of coping strategies including hand-roguing, application of inorganic fertilizer, manures and composts, and crop rotations (Emechebe et al., 2004).

However, control is most effective if a range of practices are combined into a program of integrated striga control (ISC) that can provide sustainable control over a wide range of biophysical and socio-economic environments (Berner et al., 1997; Ellis-Jones et al., 2004; Franke et al., 2006; Kamara et al., 2008). Ellis-Jones et al. (2004) showed that growing striga-resistant maize after a soybean trap crop more than doubled economic return compared with continuous cropping with local (nonresistant) maize. Franke et al. (2006) found that ISC that combined rotation of striga-resistant maize, trap crops, and fertilizer application reduced the striga soil seed bank by 46% and increased crop productivity by 88%, while Kamara et al. (2008) showed that these practices reduced striga infestation and damage on farmers fields and increased productivity by more than 200%. The latter also found that the use of a participatory research and extension approach improved community and group cohesion and relationships between farmers and extension agents, resulting in farmer-to-farmer transfer of knowledge and widespread adoption of ISC.

A range of technologies have been tested for controlling striga and yellow witchweed in cowpea, including cultural practices, chemical control, biological control, and host plant resistance (Singh and Emechebe, 1997). Among these, the use of resistant varieties is the most feasible, sustainable, and appropriate solution. Several cowpea varieties resistant to striga and yellow witchweed have been released to farmers in Africa, including IT89KD-374 (Sangaraka) and IT89KD-245 (Korobalen) in Mali; IT90K-76, IT90K-82-2, and IT97K-499-35 in Nigeria; and IT90K-59 in South Africa (Singh, 2002).

Drought

There is a clear trend of decreasing rainfall and increasing temperatures in the dry savannas of West Africa (Dai et al., 2004). According to projections by van den Born et al. (2000), by 2050 temperature in West Africa will be 1.5 to 2.5 °C higher than at present and precipitation 100 to 400 mm/yr lower. Current vegetation zones will shift towards the South, as will aridity. Jagtap (1995) showed that annual rainfall in Nigeria declined between 1961–70 and 1981–90, with delays in the onset of the rainy season and reduction in early rainfall, which shortened the growing season by nearly one month. There were fewer wet days and higher rainfall intensities in most of the country. The rainfall series showed prolonged dry periods, especially since 1970. The rainfall decline is unprecedented in duration, spatial, temporal character and seasonal expression.

Some 21% of the maize area in sub-Saharan Africa often suffers from drought stress (Heisey and Edmeades, 1999). Drought is also the main abiotic constraint responsible for low and unstable yields in groundnut. Drought also increases the probability of aflatoxin contamination on groundnut and its products. In the dry savanna zone of West Africa, the probability of drought is highest at the start and end of the growing season, but the timing of deficits is unpredictable. Because of this, the effects of drought cannot be avoided by either genotype maturity or planting date. Decreasing the susceptibility of a crop to drought, while maintaining or increasing yield in good rainfall years, would increase and stabilize rural incomes, reduce the chronic food shortages that plague these areas prior to harvest, and lessen the risk of farming.

There is growing consensus that restoration of soil fertility and conservation of soil and water resources are the starting points for agricultural transformation and development in West Africa (Rockström et al., 2010; Vanlauwe et al., 2010; Bationo et al., 2011; Oduol et al., 2011). Several strategies have been developed for the conservation of soil and water to maintain productivity in West Africa, including rainwater harvesting, live barriers, supplementary irrigation, minimum tillage, mulching, bunded basins, and tree planting (Drechsel et al., 2004).

A central approach to increase crop production in the dry savanna is planting well-adapted cultivars at the optimum date. The short growing season and frequent droughts in the dry savanna require early- and extra-early-maturing crop cultivars with drought tolerance. Breeders at International Institute of Tropical Agriculture (IITA) and partner institutions have developed maize, cowpea, and soybean cultivars that are early maturing; tolerant to drought, high temperatures, and low soil nutrient contents; and are resistant to pests and diseases (see, for example, Badu-Apraku, 2005; Kamara et al., 2005; Menkir et al., 2009).

Competition between crops and livestock for resources

Among the tremendous challenges facing agriculture in the dry savannas of West Africa, is the need to generate enough food for people and feed for animals without destroying the natural resource base. Traditional farming systems are breaking down under human and livestock population pressure. Competition is increasing between crops and livestock, particularly for land and labor (Okoruwa et al., 1996). In subhumid ecological zones, rangelands are rapidly being converted to cropland (McIntire et. al., 1992) with consequent shrinkage of traditional livestock grazing areas. As a result, livestock increasingly depend on crop residue for feed. Also, as savanna zones are progressively transformed from the traditional extensive fallow systems to continuous cropping, yields of crops and land productivity are declining and sustainability is threatened. Integration of crop and livestock offers a viable approach to sustainable intensification of land use (Ajeigbe et al., 2001), since cultivated areas can support more livestock during the dry season than non-cultivated areas if the crop residues are judiciously used. Van Raay (1975) reported that in the semi-arid areas of northern Nigeria, cattle resident in farming areas are better able to meet their protein requirement than transhumant cattle. However, as shown in Table 1, the use of crop residues as fodder removes soil nutrients (Powell and Williams, 1995), as does the harvesting and removal of grain and fodder (Mortimore et al., 1997).

Livestock have a vital role to play in maintaining or increasing the yields of cereals and certain cash crops in the dry savannas of West Africa, through provision of animal traction and organic fertilizer and diversification of production systems (Harrison, 1991; CIRAD, 1996; Smith et al., 1997; Brock et al., 2002; Williams et al., 2004; Franke et al., 2010). CIRAD (1996) noted that a farmer who works his or her land by hand can cultivate only 0.4 ha, but can cultivate 5 ha with the help of two oxen. Dual-purpose (food and feed) cowpeas, groundnuts, and other leguminous crops can provide food for humans, feed for livestock, and supply of nitrogen to the soil (Singh et al., 2003). Singh and Ajeigbe (2007) and Ajeigbe et al. (2010) document the benefits of an improved cereal–legume–livestock system adopted by 20,000 farmers in the savanna zone in Nigeria and Niger. Stall-feeding sheep and goats with cereal and legume stover during the dry season increased liveweight gains and animal fertility, increased the quality of manure that the farmers could collect and return to their fields, and allowed closer monitoring of animal health, increasing the overall productivity of the system. The system also resulted in positive residual soil N contributions to following crops, boosting crop yields (Sanginga et al., 2003).

In the past decade it has been recognized that farmers in mixed crop–livestock systems sometimes value the crop residues as much as the grain owing to their importance as a feed for livestock, particularly in the dry season (Blümmel et al., 2003; Blümmel and Rao, 2006). Breeding programs for these crops are increasingly being adapted to include breeding for residue quality without compromising grain yield.

Utilization of crop residues as livestock feed is, however, not without implications for crop production (Giller et al., 2009; Valbuena et al.,

Table 1. Nutrient (%) removal by 100 kg of grain and fodder in harvest.

Nutrient	Cowpea grain (100 kg)[1]	Cowpea fodder (100 kg)
Nitrogen	2.37	1.19
Phosphorus	0.15	0.13
Potassium	2.02	1.38
Magnesium	0.58	0.33
Calcium	0.50	0.89

1. Equivalent to 128 kg unthreshed.

SOURCE: Mortimore et al. (1997).

2012). For example, Kang (1993) showed that crop-residue management could affect cowpea grain yield. Use of crop residue as mulch together with application of fertilizer gave significantly higher grain yield than fertilizer without crop residue. Where crop residue and weeds are collected and used as fodder, the resulting animal manure should be returned and used as fertilizer. Singh and Ajeigbe (2000) showed that row planting of two rows of cereal interspersed with four rows of cowpea produced more grain and better-quality fodder than the traditional system of alternating rows of cereal and legume. This so-called "strip cropping" allows the two crops to be cultivated independently but provides for them to interact agronomically (Ajeigbe et al., 2005).

Clearly, there is a continuing need to develop improved integrated crop–livestock systems that minimize competition for scarce resources (particularly land and labor) and maximize the synergies between the components (Figure 1).

Weak extension services

Many technologies have been developed that have the potential to increase agricultural production in West Africa, but their adoption by farmers remains limited (Bationo and Baidu-Forson, 1997; Diouf et al., 1998; Ndjeunga and Bantilan, 2005). Researchers have identified a range of technical, socio-economic, institutional, and policy constraints to technology uptake, including weak extension services, weak markets for both inputs and outputs, and poor infrastructure. For instance, extension recommendations are sometimes inappropriate or ineffective. The promotion of manure application without warning that it may reduce yields under limited rainfall is a case in point (Affholder, 1994). Likewise, use of mineral fertilizers is widely promoted by research and development organizations as a blanket recommendation irrespective of zonal, climatic, and geological diversity (Diouf et al., 1998). Often a technology that worked well on station has not been adapted to farmers' conditions.

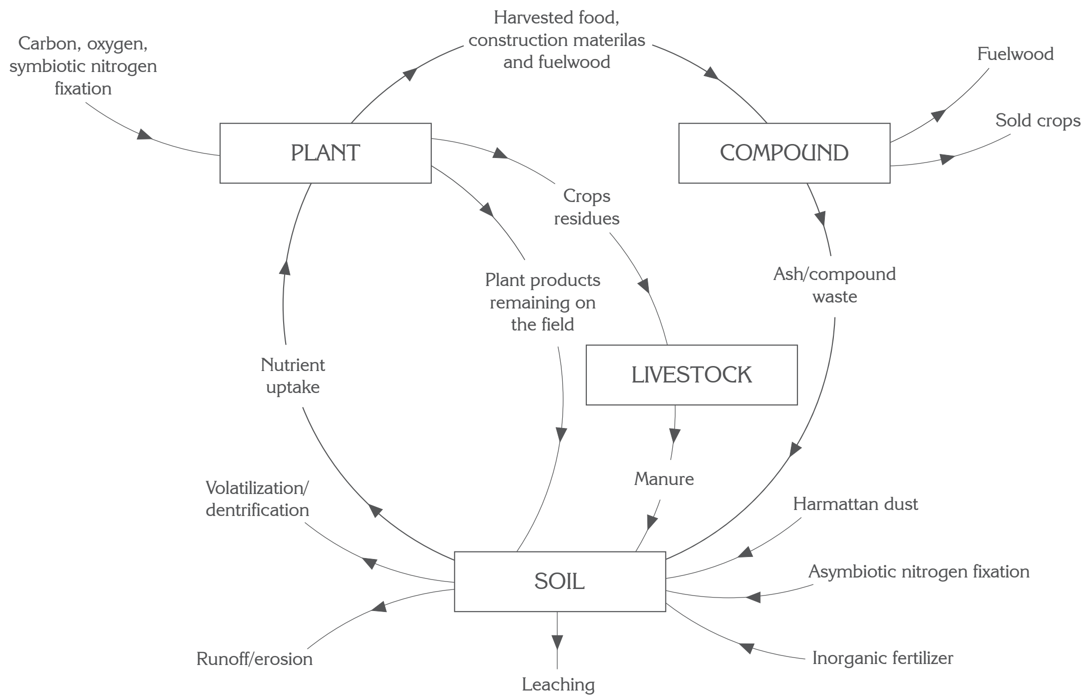

Figure 1. An example of a nutrient cycle in a mixed crop–livestock farming system.
SOURCE: Mortimore et al. (1997).

Poor communications among farmers, extension agents, and researchers has often led to poorly targeted research or to the poor adoption of promising options generated by research. Extension workers are expected to disseminate agricultural knowledge and technologies to rural communities which include production, postharvest, and livestock issues, yet they do not possess adequate knowledge in all these areas. The lack of continuing education opportunities is a drawback to extension workers' performance. This poor performance of extension efforts calls for fresh approaches (Mercoiret et al., 2003). For example, farmer participatory research and participatory learning have been adopted to make research results more understandable and useful to target groups (Farrington and Martin, 1988; Chambers et al., 1989; van de Fliert and Braun, 2002). Participatory extension models, such as farmer field schools and local agricultural research committees, make agricultural technologies quickly available and easily accessible in farming communities and enable participating organizations to gain experience in developing researcher–farmer–extension partnership (Braun et al., 2000).

Conclusions

Crop–livestock systems are intensifying in the dry savannas of West Africa because of increasing population pressure. Despite the high potential for crop and livestock production, the intensification of land-use systems faces increasing biotic and abiotic constraints. Poor soil fertility, parasitic weed infestation, drought, pests, and diseases are major constraints to food and feed production in the dry savannas. Over the years research institutions have developed and disseminated component technologies that can improve system productivity when deployed in an integrated manner. Government and national institutions in West Africa are encouraged to scale-out these technologies to wider areas for increased benefit to farmers.

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