Classification and description of the major farming systems incorporating ruminant livestock in West Africa

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Abstract

A classification of the major ruminant livestock production systems in West Africa is proposed. The proposed typology has two major classes of systems—sole livestock and crop–livestock. The sole livestock class has two systems (rangeland-based and landless) and the crop–livestock class has three sub-classes (annual crop–livestock, tree–crop–livestock and irrigated/flooded cropland–livestock). Within the 3 crop–livestock sub-classes 13 systems defined by the dominant crops are identified. The systems, including the specific roles of crops and livestock are described, their feed production potential is assessed, and the factors likely to be driving their evolution are discussed. The large majority of producers in these systems are poor and their land and animal holdings are small. Pastoral systems evolve in response to risks associated with uncertainty of rain and the demand for live animals in the highly populated and more urbanised wetter zones. Crop–livestock systems are more labour-intensive, in some cases they include animal traction, and are characterised by higher use of agricultural inputs such as fertilisers, pesticides and feed supplements. Landless, stall-feeding systems, which exist alongside or within other systems evolve primarily in response to demand for meat and are frequently associated with religious events. The proposed typology offers a framework for identifying development priorities and research opportunities. It can assist in targeting efforts to develop animal agriculture into more intensive forms of production with stronger linkages to markets, in ways that the increasing demand for food is met and opportunities for improving the livelihoods of small-scale livestock and crop–livestock producers are exploited.

Key words: Crop–livestock systems, landless livestock systems, livestock systems, rangeland-based livestock systems, tree–crop–livestock systems, West Africa.

Introduction

West Africa covers an area of about 7.3 million km^2 divided into four principal agroecological zones: arid, semi-arid, subhumid and humid (ILCA 1987; Jahnke 1982) on the basis of plant growth days (PGD) and amount and distribution of rainfall (Figure 1). The fifth agroecological zone of sub-Saharan Africa, i.e. the highlands, based on altitude and its effects on temperature during the growing period, is not significantly applicable to West Africa. The major characteristics of the arid, semi-arid, subhumid and humid zones of West Africa are summarised in Table 1. West Africa's human population was recently estimated at 263 million people, with 51% depending on agriculture and 39% living in urban centres (Thornton et al. 2002; FAO 2003). With growth rates of about 3% per annum, it is projected that by 2020 human population in West Africa will reach about 370 million, of which 42% will live in rural areas and 35% will be engaged in agriculture (FAO 2003). Agriculture is the basis of the economies of all West African countries and contributes about 35% of their gross domestic product (GDP). Poverty is widespread, and it is common for more than 80% of the inhabitants in the poorer countries in the region to live on less than US$ 1/day (World Bank 2001).

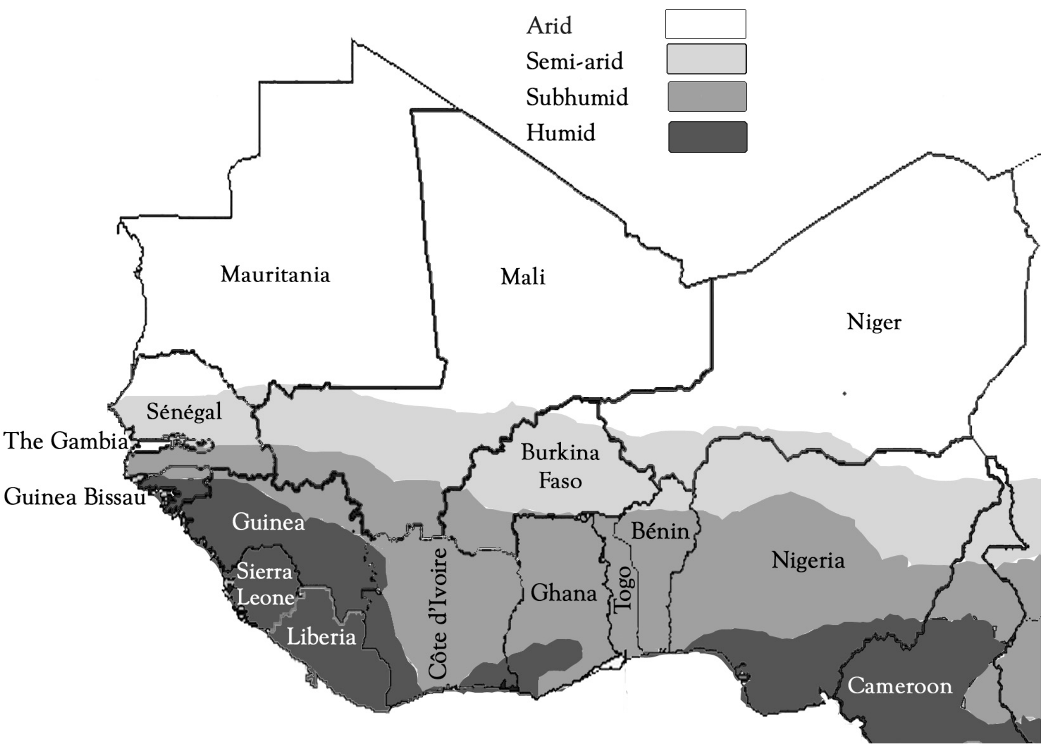

Figure 1. *Agro-ecological zones of West Africa (see Table 1 for characteristics).*

Table 1. *Characteristics of agro-ecological zones of West Africa (see also Figure 1).*

Zone	Plant growing days per annum (PGD)	Annual rainfall (mm)[1]	Area (10^6 km^2)	Area (% of total)[1]	Total human population 1990[2] (%)	Distribution of population: Cattle[3] (%)	Distribution of population: Sheep and goats[3] (%)	Cattle numbers (10^6) 2000	Sheep and goat numbers (10^6) 2000	Cattle, sheep and goats TLU (%) 2000[3]
Arid	<90	0–500	3.94	54	6	25.8	42.3	9.9	48.2	36.1
Semi-arid	91–180	500–1000	1.46	20	25	38.2	29.0	14.7	33.1	32.8
Subhumid	181–270	1,000–1,500	1.17	16	28	28.3	18.2	10.9	20.7	23.7
Humid	>270	>1,500	0.73	10	41	7.7	10.5	3.0	12.0	7.4
Total	–	–	7.30	100	100	100	100	38.4[4]	114.0[4]	100

Sources: 1. Winrock (1992), 2. WALTPS (1996), 3. Calculated based on Winrock (1992, p.17, Table 4.2) adjusted by redistributing highland *pro rata* into applicable ecological zones, 4. Kristjanson et al. this volume.

Population growth, urbanisation trends and rising incomes are leading to a rapidly growing demand for food, in particular that of animal origin. Although West Africa has one of the world's highest population growth rates, the countries in the region are also among those in the world with the lowest increases in agricultural productivity. The modest increases in agricultural output that arise from farmer-generated technical change are not capable of sustaining high rates of population increases (Pingali and Binswanger 1998).

Rural poverty in the region can be reduced through lowering transaction costs and enabling poor smallholder producers to benefit from the increasing orientation of livestock and crop–livestock production toward the markets, driven by the demand for food of animal and plant origin in urban centres. Development strategies call for approaches to identify groups of producers with broadly similar production strategies, constraints and investment opportunities. To this end, this paper attempts to identify, classify and characterise the major livestock and crop–livestock production systems of West Africa.

In the next section, an overview of typologies of the world's livestock production systems and their advantages and limitations for application in West Africa is presented. The typology of livestock production systems in West Africa proposed in this paper is then described. The productivity of food–feed crops, as it determines to a large extent the stocking potential of crop–livestock systems, is discussed to provide a background for a more detailed characterisation of the individual systems. The paper concludes with a discussion on the evolution of livestock systems, in which, as an illustration of the potential use of the proposed typology, some opportunities for their development are highlighted.

Overview of typologies of the world's livestock production systems and their relevance for West Africa

In the context of this paper, a system is defined as a 'population of farms that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate' (Dixon et al. 2001). Following this definition, a classification or typology of production systems should be useful in the design of development strategies, in particular for identifying target populations and priorities and opportunities for development.

One of the simplest classifications of livestock production systems was proposed by Jahnke (1982), who identified two broad systems: range–livestock and crop–livestock. With the exception of emerging intensive, stall-fed, urban and peri-urban livestock systems, Jahnke's classification covers the rest of the livestock and crop–livestock production systems that exists in West Africa. For crop–livestock systems, Jagtap and Amissah-Arthur (1999) used three criteria (use of crop residues, use of manure, and use of animal traction) to propose three classes of systems based on their stage of development: no integration, early integration, and full integration. These two typologies do not reflect the fact that the production potential of the resources that sustain these systems is influenced by agro-ecological conditions, and therefore has limited applicability for development purposes.

The influence of the agro-ecological potential on the types of crop–livestock production systems was recognised by Seré et al. (1996), who identified 11 ruminant and monogastric livestock production systems (Figure 2). This classification was based on the agro-ecological environment, the level of integration of crops with livestock production and the availability and type of land used for livestock production. Out of the 11 systems, the three systems in temperate zones, grassland-based (GLT), mixed, rainfed (MRT) and mixed irrigated (MIT) do not apply to West Africa and the industrial, landless monogastric system is limited to poultry alone. This leaves seven ruminant production systems that should be considered as relevant to West Africa. Seré et al. (1996) also considered irrigated crop–livestock and industrial livestock systems in West Africa insignificant and these were not accounted for in their global analysis. Hence, production activities in the mixed, irrigated, humid/subhumid (MIH), mixed, irrigated, arid/semi-arid (MIA) and industrial systems were not allocated land size nor stock numbers, thus leaving the grassland and mixed, rainfed systems of the humid/subhumid and arid/semi-arid zones as the only 'functional' production systems in the region.

Thornton et al. (2002) and Kruska et al. (2003) expanded the classification of livestock systems proposed by Seré et al. (1996) to introduce human population density as a factor to describe livestock production systems, made modifications to suit current data on irrigated systems and used a combination of population density (Deichmann 1996) and Night-time Lights of the World database (NOAA 1998) to define possible landless or industrialised livestock production systems. The inclusion of demographics is important since in rural areas livestock density and human population are positively correlated (Wint and Bourn 1994) and the settlement pattern is often in line with the agricultural potential of land (Vierich and Stoop 1990).

Specific classes	Broad classes
Grassland-based, temperate (GLT)	Grazing (livestock only)
Grassland-based, humid/subhumid (GLH)	
Grassland-based, arid/semi-arid (GLA)	
Mixed, rainfed, temperate (MRT)	Mixed (crop–livestock), rainfed
Mixed, rainfed, humid/subhumid (MRH)	
Mixed, rainfed, arid/semi-arid (MIA)	
Mixed, irrigated, temperate (MIT)	Mixed (crop–livestock), irrigated
Mixed, irrigated, humid/subhumid (MIH)	
Mixed, irrigated, arid/semi-arid (MIA)	
Landless, monogastric (meat, eggs)	Industrial
Landless, ruminant meat	

Figure 2. *Classification of the world's livestock production systems proposed by Seré et al. (1996)*

The classification system proposed by Seré et al. (1996) and expanded by Thornton et al. (2002) and Kruska et al. (2003) is amenable in identifying priorities at a regional (e.g. South Asia, West Africa, etc.) and country (e.g. India, Nigeria, etc.) level. However, an important shortcoming of this typology is that it does not take into account the dominant crops in the various locations as key determinants of mixed farming systems. This shortcoming limits greatly its applicability for development purposes, as it does not offer insights to potential interventions that could improve the livelihoods of livestock keepers. This limitation becomes even more crucial as agricultural intensification occurs, because livestock will increasingly depend on crop residues and less on grazing on range, fallows and marginal areas (Smith et al. 1997; Naazie and Smith 1997).

Wint et al. (1999) proposed a classification of farming systems in Africa (Plate 8) on the basis of the predominant type of agricultural activity. Human population, cultivation and cattle density were used to define the following seven farming systems:

- Minimal – with very low levels of agricultural activity of any description
- Livestock-oriented – with moderate cattle densities and low cultivation levels
- Intensive pastoral – with high cattle densities and moderate to low cultivation levels
- Agro-pastoral – with moderate cattle densities and relatively high cultivation levels
- Mixed – with moderate cattle and cultivation levels
- Arable – with high cultivation levels and low cattle densities
- Intensive – with high densities of cattle and high percentage cultivation.

Following Wint et al. (1999), intensive pastoralism occurs only in the elevated regions of Nigeria. Mixed farming is most evident in the semi-arid and subhumid zones, especially in Nigeria, and is bordered to the north by agro-pastoralism, and to the south by arable farming which predominates nowhere else on the continent. However, the patterns that emerge from this classification could not be easily interpreted to fit a framework of human population and PGD. Given that different ecological zones do not support uniform categories of agricultural production, Wint et al. (1999) recommended that future efforts at classifying farming systems should incorporate levels or production of zone-specific crops, and additional livestock species—most notably small ruminants—in order to produce applicable distributions of farming systems.

The concerns of Wint et al. (1999) were addressed at least in part by Dixon et al. (2001), who specified seven broad types of systems and 72 specific systems in the world. Of these, 14 systems exist in sub-Saharan Africa and the following 8 in West Africa:

1. Irrigated
2. Tree crop
3. Root crop
4. Cereal–root crop mixed
5. Agro-pastoral mixed pearl millet/sorghum
6. Pastoral
7. Sparse arid
8. Coastal artisanal fishing (Plate 9).

The general criteria used for the definition of farming systems by Dixon et al. (2001) were:

- Available natural resources, including water, land, grazing area and forest; climate – of which altitude is an important determinant; landscape including slope; and farm size and tenure, in relation to access to different resources
- Dominant farm activities and household livelihood pattern (e.g. crops, livestock, trees, aquaculture, hunting and gathering, off-farm activities); technologies and the resulting intensity of production and integration of crops and livestock; and farm management and organisation (e.g. family, corporate, cooperative, etc).

In contrast to the classification by Seré et al. (1996) expanded by Thornton et al. (2002) and Kruska et al. (2003), the one proposed by Dixon et al. (2001) recognises that different crops exist in mixed systems and that crop-specific crop–livestock systems are not limited to a particular agro-ecological zone. However, a more comprehensive distribution of crop-based systems in the region than the one used by Dixon et al. (2001) is now available (Manyong 2002). This new classification of crop-based systems can be used to further disaggregate the grouping of crops and, therefore, to identify specific crop–livetsock systems. This would also facilitate the estimation of feed availability to assess a system's stocking potential. For instance, rather than using cereals in general, the identification of such crops as maize, sorghum or pearl millet would be more accurate because of their different yields per hectare, grain to stover ratio, proportion of edible material in total biomass, and nutritional values (Bationo et al. 1995; de Leeuw 1997).

Classification of crop-based agricultural systems in West Africa

In 1996 the International Institute of Tropical Agriculture (IITA) completed a country-level characterisation of agricultural systems in West Africa including participatory mapping of dominant crop production systems at the district level (Manyong et al. 1996). These maps were later recombined to arrive at national and then regional-level distribution of crop production systems in West and Central Africa. The exercise led to the identification of about 100 farming systems based on a vector of 32 variables. These preliminary systems were reclassified based on primary crops e.g. maize-based, yam-based, cassava-based or sorghum-based systems, and the relative importance of each crop-based system within the sub-region. Based on area covered by the main crop the dominant systems included those based on: yam (20.4%), sorghum (16.7%), maize (15.2%), rice (13.2%), cocoa (10.9%), cotton (8.1%) and cassava (7.8%) as the predominant systems. This study omitted the pearl millet-based systems in the semi-arid agro-ecological zone. Manyong (2002) updated the IITA study and included the pearl millet-based systems. Based on the major intercrop combination of maize, sorghum, pearl millet, groundnut, cowpea, cotton, cassava, yam, cocoa, oil palm, coconut and plantains, Manyong (2002) defined 10 specific agricultural production systems, along a PGD gradient. These are listed in Plate 10.

Manyong (2002) based his classification of farming systems on crops and to a large extent excluded the livestock component of these systems. Only two systems, maize–sorghum–cattle and pearl millet–cowpea–cattle, include a livestock component, even though it is known that crop–livestock integration exists in all the systems, albeit to widely varying degrees. The flooded inland valleys and plains (many of which occur along the course of the Niger and Gambia rivers), where rice–livestock production systems predominate, were not marked out distinctly. Also, the range–livestock or pastoral system is not represented. Nonetheless, Manyong (2002) provides the most consistent crop-specific, regional classification of farming systems in West and Central Africa, using the same set of criteria for all countries involved in the study. As this classification contains all the dominant crops in the region, and given the increasing importance of crop residues as livestock feed, it offers a solid basis for a more focused identification of crop–livestock systems in the region.

A proposed typology of livestock production systems in West Africa

Using a combination of elements from Seré et al. (1996), Dixon et al. (2001), Manyong (2002) and Thornton et al. (2002), a classification of livestock production systems for West Africa is proposed. The proposed typology (Figure 3) has two major classes and 15 systems. The two major classes are sole livestock and crop–livestock systems. The sole livestock class has two systems (rangeland-based and landless) and the crop–livestock class has three sub-classes (annual crop–livestock, tree-crop–livestock, and irrigated/flooded cropland–livestock). Within the three crop–livestock subclasses 13 systems are identified based on the dominant crops. In order to characterise these systems, their

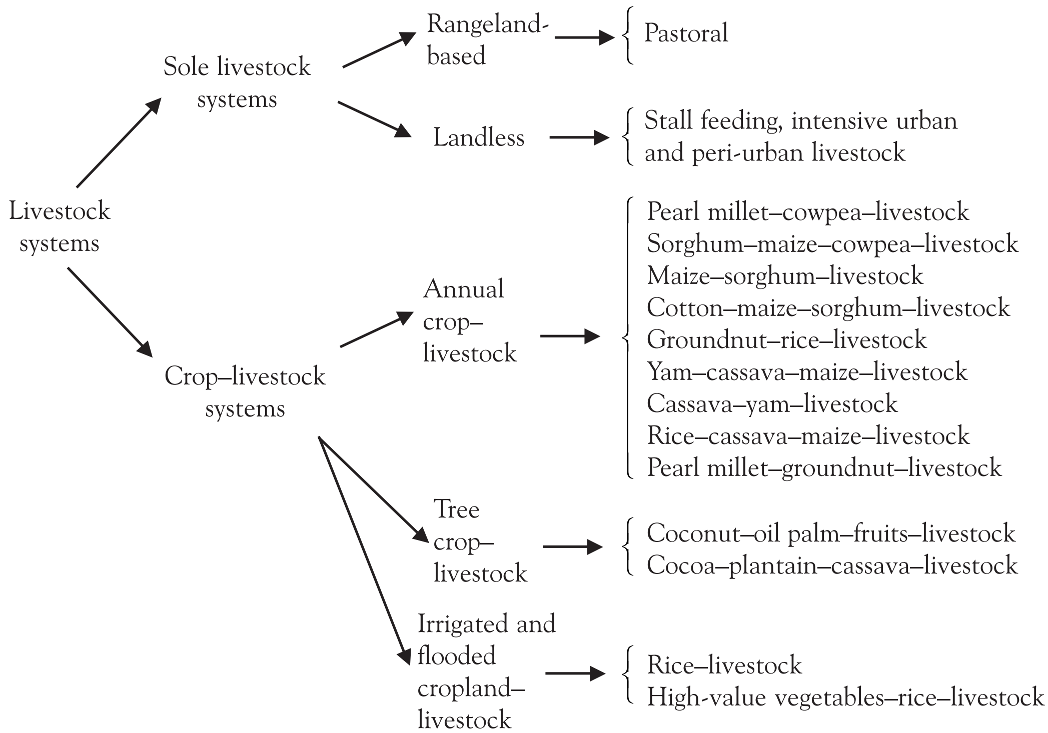

Figure 3. *Proposed typology of livestock production systems in West Africa.*

boundaries were defined to enable the overlaying of spatial databases containing relevant information in order to calculate and analyze their properties. Considering the strong points of some of the existing classifications, the boundaries of the systems included in the proposed typology were outlined as follows:

- **Pastoral**—based on the grassland-based arid and semi-arid system (GLA) in Seré et al. (1996).
- **Stall-feeding, intensive urban and peri-urban livestock**—based on the possible industrial landless production systems defined in Thornton et al. (2002). However, stall feeding also exists in rural settings (mainly for festival fattening of sheep) and in some major livestock markets to recondition stock before reselling them—usually in the same market. Thornton et al. (2002) used Landless Metropolitan Systems (LMS), i.e. high population density areas (>450 person/km^2) with significant urban infrastructure and city lights, and Landless Systems (LS), i.e. high population density areas (>450 person/km^2) with no city lights. Both LMS and LS were derived by combining population density and Night-time Lights of the World (NOAA 1998).
- **Rainfed crop–livestock**—based on Manyong (2002) extended from 10 to 11 systems and modified to include livestock in all systems. It is recognised that the level of crop–livestock integration varies greatly between these systems.
- **Irrigated and flooded cropland–livestock**—based on irrigated and rainfed irrigated land in Dixon et al. (2001) merged with Manyong (2002) to define high-value vegetable–rice–livestock and rice–livestock systems.

The shapefiles of the relevant portions of the above classification were combined using ArcView GIS 3.2® (ESRI 1999) to produce a map of the crop–livestock systems of West Africa (Plate 11). Because the urban, peri-urban stall-feeding system is spread across the region, for clarity the distribution of this system alone, derived from Thornton et al. (2002), is presented in Plate 12. The map shown in Plate 11 provided the basis for calculating basic statistics for all systems using data from the following sources: cattle population densities and tropical livestock unit (TLU) population densities (ILRI databases); sheep and goat population densities (FAO country statistics); percentage cultivation (ILRI databases) and human population densities (Deichmann, 1996). A summary of these statistics for all systems is presented in Table 2.

Productivity of food–feed crops, a key factor determining stocking potential of the major crop–livestock systems in West Africa

Because of the bulky nature of basal feeds, transfer of feeds across systems is rather limited. In general, it is more economical to move animals to areas where potential for feed production is high. Intensive dairy and fattening operations evolve in areas where

Table 2. *Characteristics of 15 livestock production systems of West Africa.*

Production system	Area (km²)	% of total area	Total population in 2000 ('000) Human	Cattle	Sheep and goats	TLU	% of total TLU	Mean population density (km²) Human	Cattle	Sheep and goats	TLU	Mean cultivation (%)
Pastoral	908,721	25.1	5,099	4,639	24,802	7,976	18.1	5.6	4.8	27.3	9.4	4.5
Stall feeding–intensive urban and peri-urban	52,642	1.5	55,346	412	2,135	663	1.5	1051.4	7.3	40.6	14.6	24.4
Pearl millet–cowpea–livestock	641,124	17.7	39,289	8,864	24,176	11,808	26.8	61.3	13.5	37.7	19.4	25.2
Pearl millet–groundnut–livestock	62,509	1.7	3,975	711	2,518	1,167	2.6	63.6	11.1	40.3	19.3	24.6
Sorghum–maize–cowpea–livestock	231,549	6.4	9,784	3,259	9,418	4,528	10.3	42.4	13.9	40.7	19.9	16.0
Maize–sorghum–livestock	237,654	6.6	16,247	2,702	8,492	3,851	8.7	68.8	11.0	35.7	16.7	21.5
Rice–groundnut–livestock	27,407	0.8	1,014	228	541	287	0.7	37.0	8.3	19.8	14.9	5.4
Rice–livestock	339,844	9.4	15,937	3,238	10,009	4,497	10.2	47.0	9.2	29.5	14.6	12.8
High-value vegetables–rice–livestock	91,270	2.5	5,071	1,090	2,529	1,348	3.1	57.7	11.7	27.7	16.8	19.4
Cotton–maize–sorghum–livestock	107,692	3.0	2,306	990	1,727	1,224	2.8	21.4	9.0	16.0	11.5	14.1
Rice–cassava–maize–livestock	259,042	7.1	7,406	1,111	1,776	1,145	2.6	28.6	4.1	6.9	5.1	3.3
Cassava–maize–yam–livestock	136,518	3.8	13,643	408	4,361	967	2.2	99.9	2.8	31.9	8.1	12.8
Yam–cassava–livestock	297,153	8.2	14,713	2,504	10,197	3,849	8.7	49.5	8.1	34.3	13.7	13.4
Cocoa–plantain–cassava–livestock	187,290	5.2	17,563	158	3,152	586	1.3	94.5	0.6	16.8	4.4	13.2
Coconut–oil palm–fruits–livestock	46,581	1.3	5,127	79	1,028	202	0.5	110.5	1.4	22.1	7.2	22.0
Total (mean)	3,626,997	100	212,521	3,0391	106,862	44,099	100	(58.6)	(8.4)	(29.5)	(12.2)	(13.7)

the greater feed availability allows for more efficient production of meat and milk. Likewise, pastoral and agro-pastoral producers move their herds to take advantage of the seasonal availability of grasses in the rangelands in the arid zones and crop residues in the cultivated areas of the semi-arid and subhumid zones. Therefore, an important factor in characterising livestock systems is the potential stocking capacity as determined by feed supply. In the case of crop–livestock systems this is defined to a large extent by the biomass produced by crops that could be available for use as livestock feed.

The major food–feed crops in the mixed systems identified above are pearl millet, sorghum, maize, rice, cowpea, groundnut, cassava, yam, cocoa, oil palm, coconut, vegetables and fruits. Residues from these crops obtained after harvest provide feed for livestock throughout the dry season. Figure 4 shows trends in the production of these crops in West Africa between 1980 and 2000 and in particular the sharp increase in the production of tubers (cassava and yams), which more than tripled over the same period, from 25.8–81.9 million mt.

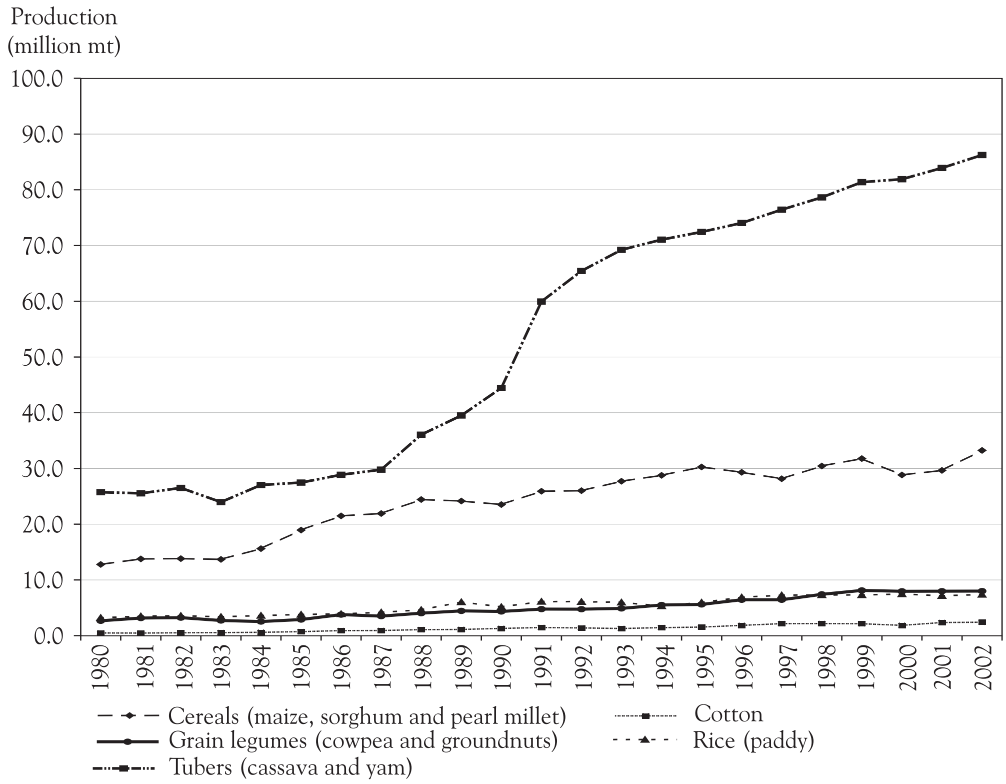

Figure 4. *Crop production in West Africa 1980–2002 (FAO 2003).*

The stocking potential that can be sustained by food–feed crops was estimated for the 15 systems. This estimation considered the percentage of cultivated land and dominant crops within the system and the average residue yield/ha. For instance, for the pearl millet–cowpea–livestock system, residues were assumed to come only from pearl millet and cowpea although it is known that the system has also groundnut, sorghum and other by-products. In the case of intercrops, the cropping geometry was used to derive the consolidated area under each crop. For the pearl millet–cowpea–livestock system, Singh and Tarawali (1997) reported two rows of pearl millet to one row of cowpea giving about 67% of the farm area to pearl millet and 33% to cowpea in the wetter semi-arid zone around Kano, Nigeria. The average residue yields of the dominant crops within the relevant agro-ecology were obtained from the literature. For instance for the pearl millet–cowpea–livestock system, Powell and Fussell (1993) estimated 1.23 t dry matter (DM)/ha as the edible biomass of residue from pearl millet, while Singh and Tarawali (1997) reported a yield of 0.25 – 0.48 t/ha of DM for cowpea intercropped with pearl millet. Straw:grain ratios of 3:1 for pearl millet and sorghum, 2:1 for maize, 1.5:1 for cowpea and groundnut and 2.5:1 for rice were assumed (Zongo 1997; as cited by Savadogo, 2000). As much as two-thirds of the residues, particularly those from pearl millet, sorghum, maize and rice are used as domestic construction materials, fuel or soil amendments. Conservative figures for the proportion of residues from these crops that would be used as feed were 33% of residues from sorghum, pearl millet, maize and rice and 67% of cowpea and groundnut haulms. A daily feed consumption of 6.25 kg DM of residue per TLU[1] for 90 days/year is common among agro-pastoralists in the semi-arid zone and for 120 days/year in the subhumid zone (van Raay and de Leeuw 1974; Powell and Bayer 1985; Savadogo 2000).

Where a crop–livestock system was found in more than one ecological zone (which makes the estimation of average yields of crops and their residues more difficult) or where farm survey data for some crops in a system/location were not available, the estimates for the total amount of crop residues were based on average yields for West Africa (FAO 2003). According to FAO (2003), average yields in West Africa in 2000 were: cassava 10.05 t/ha, cotton seed 0.97 t/ha, cowpea 0.33 t/ha, groundnut 0.97 t/ha, maize 1.12 t/ha, pearl millet 0.71 t/ha, rice 1.70 t/ha, sorghum 0.88 t/ha, and yam 9.7 t/ha. The stocking capacities supported by food–feed crops are summarised in Table 3.

Characteristics of the major livestock and crop–livestock production systems in West Africa

In describing the various livestock and crop–livestock production systems, mention is made of the agro-ecological or geographical zone in which significant portions of the

1. 1 TLU = a hypothetical animal of 250 kg liveweight.

Table 3. *Number of tropical livestock unit (TLU)-months supported by useable crop residues in crop–livestock production systems of West Africa.*

Production system	Cultivated area (km^2)	Useable crop residue (10^6 kg DM)	Useable crop residue/TLU in system/year (kg DM)	Number of TLU-months supported/year
Pastoral	40,914	2,876	361	1.9
Stall feeding–intensive urban and peri-urban	12,836	364	549	2.9
Pearl millet–cowpea–livestock	161,559	7,167	607	3.2
Pearl millet–groundnut–livestock	15,357	580	497	2.7
Sorghum–maize–cowpea–livestock	37,094	2,947	651	3.5
Maize–sorghum–livestock	51,094	4,632	1,203	6.4
Rice–groundnut–livestock	1,478	167	583	3.1
Rice–livestock	43,357	6,081	1,352	7.2
High-value vegetables–rice–livestock	17,683	818	607	3.2
Cotton–maize–sorghum–livestock	15,133	1,380	1,127	6.0
Rice–cassava–maize–livestock	8,578	1,236	1,079	5.8
Cassava–maize–yam–livestock	17,540	1,998	2,067	11.0
Yam–cassava–livestock	39,799	5,417	1,407	7.5
Cocoa–plantain–cassava–livestock	24,701	993	1,694	9.0
Coconut–oil palm–fruits–livestock	10,270	212	1,047	5.6
Total (mean)	497,432	36,870	(836)	(4.5)

systems exist. Readers are referred to Figure 1 and Table 1 to crosscheck the general characteristics of the relevant agro-ecological zones. This section focuses on peculiar characteristics such as human and livestock populations, percentage of land area under cultivation and the capacity of crop residues from the system to sustain livestock in relation to the current stocking rate. For most systems the main forces driving their evolution are identified.

Pastoral systems

Depending on the extent of their mobility, pastoral systems fall into three categories:

1. Nomadic—constantly on the move in search of suitable pasture and water, with no home base or cropland
2. Semi-settled agro-pastoralists (transhumant)—having rights to a cropland aimed at satisfying household needs and from where some or all the livestock and household migrate at the beginning of the dry season, and to which they return at the onset of rains
3. Sedentarised agro-pastoralists—fully settled and operating integrated crop–livestock farms with smaller herd sizes but more cropland than their transhumant and semi-settled counterparts.

In the context of this paper, pastoral systems include categories 1 and 2 above. This system is located mostly in the arid zones of Burkina Faso, Mali, and Niger extending to the Atlantic Ocean through the northern parts of Senegal. The area under pastoral systems constitutes 25.1% of West Africa and contains 4.6 million cattle and 24.8 million sheep and goats, equivalent to 8 million TLU or 18.1% of all ruminant TLUs in West Africa (Table 2). Traditional, low-input, transhumant pastoral systems are prevalent, while livestock are also raised in villages by semi-settled agro-pastoralists.

The pastoral system produces and markets young animals in response to the demand for meat in urban areas, primarily in coastal cities. It also provides stock for mixed systems in areas with higher potential to produce feed for fattening or dairy operations. As a result of the biophysical properties of the arid zone in which this system exists, the mean area under cultivation is only 4.5%. Therefore crop–livestock integration does not occur at the farm level, but rather at a sub-regional level through herd mobility and crop residue grazing contracts between pastoralists and farmers in the cultivated zone.

Table 3 shows that useable crop residue in pastoral systems, estimated at 2876 million kg DM, if shared among the 8 million TLU ruminant livestock in the system would provide each TLU with 360 kg DM of crop residues/year. This would maintain each TLU for a period of about 2 months/year. Considering that the harsh dry season that characterises this system lasts at least 3 months/year, there is a deficit of a month, that has to be made up through transhumance since basal feed materials are bulky and inter-system transfer of such material is not economically feasible. In effect, transhumance is practised in response to sharp variations in annual and seasonal rainfall and feed availability, and occasional but recurrent droughts, which result in longer-distance migration and higher losses of livestock. According to Geesing and Djibo (2001), the long drought period from 1969 to 1974 caused the loss of 50% of the cattle, 30% of the sheep and 27% of the goats in Niger. Following the drought, herd structure changed in favour of keeping more small ruminants because they appear to be more resilient to drought than cattle and are also more prolific and therefore flocks can quickly be rebuilt after the drought.

In spite of the high risk of crop loss that could occur if farmers cultivate at levels below the minimum moisture required by crops, some pastoralists usually plant pearl millet close to this minimum during migration. Some pastoralists and their herds moved 150 to 250 km southwards in apparent response to persistent threats of drought. This movement is in line with the observation by Tiffen (this volume) that livestock rearing has shifted southwards in West Africa. The trend is increasingly towards cropping the areas of the arid zone bordering the semi-arid areas with the result that land available for grazing is shrinking and agro-pastoralism is evolving. The risk of conflicts between pastoralists and crop farmers is increasing along with these trends.

With human and livestock population densities of 5.6 persons/km and 9.4 TLU/km^2, this is the only one of the 15 systems where livestock population densities are higher than those of humans. This fact points to market opportunities for live animals in the wetter and more densely populated areas in the south, and not to the human population pressure within the system, as the major driver of this system. Livestock disease is not a major constraint in this zone because livestock production is limited primarily by the risks associated with the uncertainty of rains and the availability of feed.

Pearl millet–cowpea–livestock system

The pearl millet–cowpea–livestock system, like the pastoral system, stretches across much of West Africa from northern Nigeria, through south-western Niger and Burkina Faso, to the southern parts of Mali, an area corresponding roughly to the semi-arid zone. It is the largest crop–livestock production system in West Africa covering 17.7% or 0.64 million km^2 of its land area, of which 25.2% or 0.16 million km^2 are cultivated (Table 2). Pearl millet and cowpea are the predominant crops with pearl millet planted in pure stands or intercropped with cowpea. Where soil fertility and moisture permit, sorghum and maize are also grown. These crops yield an estimated 7167 million kg DM of useable crop residues/year, capable of sustaining the system's ruminant livestock population of 11.8 million TLU for a period of 3.2 months/year (Table 3). The pearl millet–cowpea–livestock system has a higher capacity to sustain its livestock population from useable crop residues than the pastoral system.

With an average cultivated area of 25.2%, a high livestock density of 19.4 TLU/km^2 (13.5 cattle/km^2 and 37.7 sheep and goats/km^2) and a human population density of 61.3 persons/km^2 putting pressure on its predominantly sandy soils, crop–livestock integration is evolving as a strategy to maintain soil fertility. Previously, the predominant mode for obtaining manure was through crop residue grazing contracts with transhumant pastoralists whose livestock deposit manure on the contracted fields. As integrated crop–livestock systems evolve, two groups of farmers are easily discernible:

1. crop-based village farmers (usually the local indigenous landowners who acquire some livestock to source manure autonomously and
2. livestock-based agro-pastoralists (from the settled or semi-settled Fulbe tribe) who have a higher capacity to produce manure but comparatively smaller areas of cropland and an unsatisfied need for crop residues for their livestock.

A study in western Niger involving 532 farmers (366 village farmers and 166 agro-pastoralists) showed that, on average, each agro-pastoralist household cropped 10.5 ha and owned 19.2 sheep, 36.4 goats, 27.6 cattle and 5.8 dairy cows enabling it to manure 4.7 ha of its cropland compared to village farm households that cropped 14.5 ha and applied livestock manure to only 1.4 ha due to their lower livestock endowment—2.2 sheep, 2.3 goats, 3.4 cattle and 0.6 dairy cows (Hiernaux et al. personal communication). While the crop residues and manure linkages between crop and livestock production are high in this system, the use of animal traction for cultivation is not widely practised because existing agro-ecological and economic conditions are not appropriate to promote profitable and intensive use (Williams 1997).

The livestock disease challenge is very low. The high rate of urbanisation along the coast and its associated changes in income and food consumption patterns create a good market for live animals and act as the principal driver of this system's evolution. The risk of drought also drives this evolution. Over the years, this risk has led to a system of entrustment of animals (*haba nai*) to guard against total loss of animals in the event of very long droughts or other unforeseen disasters.

Pearl millet–groundnut–livestock system

The pearl millet–groundnut–livestock system is found mainly in northern parts of Senegal and in most of The Gambia. Together with the pearl millet–cowpea–livestock system, this system defines a pearl millet belt that stretches across West Africa from northern Nigeria and southern Niger to northern Senegal. The pearl millet–groundnut–livestock system has an area of 62,509 km^2 and shares similar agro-ecological and farming system characteristics with the pearl millet–cowpea–livestock system (Table 2). Average livestock density is 19.3 TLU/km^2 (compared to 19.4 TLU/km^2 in the pearl millet–cowpea–livestock system) and human population density is 63.6 persons/km (compared to 61.3 persons/km in the pearl millet–cowpea–livestock system). However, major differences occur between both systems in terms of the breed of cattle raised and the wider use of animal traction for cultivation and transportation. Due to the high incidence of trypanosomosis and probably also because of cultural preferences, N'Dama cattle known for their trypanotolerance are commonly reared for both meat and milk. Itty (1992) described two livestock management systems in The Gambia: one in which the owner manages the herd (usually of the Fula tribe) and the other in which crop-based village farmers (usually of the Mandika tribe) contract the daily management of their herds to the agro-pastoralist, using milk to make full or part payment. Although their management practices differ, there is not so much difference in herd and farm sizes per household between the Fula and Mandika as there is between the Djerma and Fulbe tribes of western Niger. For example, average farm size among the Fula is 5.7 ha compared to 3.2 ha among the Mandika; household size, 7.2 vs 8.2 persons; cattle owned, 11.1 vs 7.2 TLU and small ruminants, 1.5 vs 0.7 TLU (Okike 2002a).

During the planting season animals are herded in groups to avoid damage to crops. However, after harvest all the groundnut hay is collected and stored to feed work oxen, while residues from pearl millet are left behind and animals may roam freely and graze anywhere (Agyemang et al. 1997). Useable residues from these sources are estimated at 580 million kg DM, enough to provide feed for the system's ruminant livestock population of 1.17 million TLU for 2.7 months/year (Tables 2 and 3). The industrial demand for, and price of groundnut is an important driving force of this system, with livestock providing a means for transforming and adding value to the agro-industrial by-products from groundnut production and oil extraction.

Sorghum–maize–cowpea–livestock system

The sorghum–maize–cowpea–livestock system is located in the drier parts of the subhumid zone sometimes referred to as the northern Guinea savannah (NGS). It is less continuous than the pastoral and the pearl millet systems, but is found in several locations in West Africa. This system covers an area of 0.23 million km^2, and hosts 3.3 million cattle and 9.4 million sheep and goats (equivalent to 4.5 million TLU), making it the production system with the highest density of livestock (19.9 TLU/km^2) in the region (Table 2). Being midway between systems in the drier zones with comparative advantage in livestock production, and those in the wetter zones with comparative advantage in crop production, crop–livestock integration is probably highest in this system. Farmers have been shown to operate at a higher level of production efficiency (86% on average) than farmers located in the drier systems who have an average of 68% (Okike et al. 2002b).

Although sorghum, maize and cowpea are the predominant crops, pearl millet, groundnut and some soybean are also grown. The adoption of improved varieties of food–feed herbaceous legumes is high because in addition to food and cash obtained from grain legumes, the production of fodder is a significant source of income (Inaizumi et al. 1999). Some farmers sell cowpea fodder during the dry season, when the feed shortage is critical, and there have been indications that income from fodder sales makes up a substantial proportion of their total farm income (ICRISAT 1991). Farmers are also aware that herbaceous legumes provide a source of high-quality fodder for livestock and improve soil fertility. From a basket of options, farmers have shown interest in planting *Centrosema pascuorum*, *Aeschynomene histrix*, *Stylosanthes hamata* and *Stylosanthes guianensis* accession ILRI 164 by saving their seeds for replanting during the following season on the same plots, as well as extending cultivation to other plots (Tarawali et al. 1999). One of the most popular cowpea varieties, IT90K-277-2, is an improved local variety that combines resistance to aphids, bruchids, thrips, nematodes, and some viruses that are the main biological constraints to cowpea production. With these qualities, this variety yields an average of 1.3 t/ha of grain and 2.5 t/ha of fodder in farmers' fields (Singh and Tarawali 1997). High crop residue yields sustain the crop residue balance in this system, to the extent that even though it has the highest density of livestock, the current stocking rate relative to the carrying capacity of its crop residues is only 87% (Table 3).

As in the case of the pearl millet–cowpea–livestock system, this system also includes two groups of producers, namely crop-based village farmers and sedentary agro-pastoralists. Probably due to a longer history of settlement into crop–livestock farming, the gap in resource endowment between the two groups has narrowed down compared to examples of the pearl millet–cowpea–livestock system from western Niger. Typically, the village farm household cultivates 6.8 ha, owns 5.6 TLU usually made up of two pairs of work bulls (one pair in active use and another in training as replacement) and small ruminants, and applies about 427 kg of manure/ha compared to the agro-pastoralist household cultivating 5.9 ha and owning 26.3 TLU which enable a manure application rate of 798 kg/ha (Okike 2002b).

This system is principally driven by population growth, urbanisation and good market opportunities for cowpea and meat both within and outside the system. In Nigeria, where most of the cowpea in the region is grown and consumed, there is huge market for this commodity in both rural and urban areas of the south. This demand, coupled with that for meat in the urban areas along the coast, acts in concert to drive the sorghum–maize–cowpea–livestock system.

Maize–sorghum–livestock system

The maize–sorghum–livestock system, like the sorghum–maize–cowpea–livestock system, is located in the drier parts of the subhumid zone and occupies a similar area (0.24 million km^2) of which 21.5% is cultivated (Table 2). It has a livestock population of 3.9 million TLU made up of 2.7 million cattle and 8.5 million sheep and goats. Its livestock population density (16.7 TLU/km^2) is lower than the 19.9 TLU/km^2 in the sorghum–maize–cowpea–livestock system that is similarly located in the NGS. Useable residues from maize and sorghum amount to 4,632 million kg DM, based on which its current stock of ruminants can be maintained for 6.4 months/year (Table 3).

The maize–sorghum–livestock system is strikingly different from many of the other production systems in that it is the most responsive to industrial demand for cereals. Farmers actively seek new technologies and innovations that improve their profit margins. Use of improved seeds, pesticides, herbicides, mechanical traction and chemical fertilisers is common. The inclination of farmers to replace animal traction with mechanical traction and manure with chemical fertilisers points to a diminishing importance of crop–livestock integration in this system, which seems to have attained the specialised/commercial phase of agricultural intensification described in Pingali (1995). Therefore, issues related to the implications of high external (inorganic) inputs use for environmental health and food safety become important.

Until the late 1980s, this system was based almost entirely on a single-crop system that produced maize to complement the raw material needs of livestock feed, millers, and food, beverage and confectionery industries. Policies accompanying structural adjustment programmes that were embarked upon at that time by most governments in the region forced entrepreneurs to look for local substitutes to their major raw material.

An example of this is the substitution of sorghum for barley by local breweries. In response, sorghum production is gaining popularity in the area and the adoption of varieties such as ICSV 400 developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Kano and judged to be of excellent malting quality, grew from enough seeds to plant 5 ha in 1995 to 40,000 t in 2002 (Bello 2002).

The maize–sorghum–livestock system appears to be evolving in response to demand and policies that promote: the use of cereal grains for industrial use, the availability of technology, and the demand for meat.

Cotton–maize–sorghum–livestock system

The cotton–maize–sorghum–livestock system covers an area of 0.11 million km^2 of what has become known as the cotton belt of West Africa. It has about 2.3 million people and 1.2 million TLU including about one million cattle and 1.7 million sheep and goats (Table 2). According to a survey by the Malian Institut d'economie rurale (IER), an average farmer's herd size is 4.2 work bulls, 13.8 cattle, 8.3 sheep and 3.4 goats (Sanders et al. 1996). This system has been described by Williams et al. (2000) as one of the examples of crop–livestock systems in the subhumid zone of Burkina Faso and Mali. Williams et al. (2000) reported how the introduction of new cultivars of cotton and maize combined with the rapid introduction of animal traction and improved crop management practices such as fertiliser use, increased plant density and pest control, made this system a success story.

The system is an example of the important roles of technological and institutional support in the evolution of crop–livestock production systems. Farmers knew the price of their product before planting, just as they were provided technical information and credit for the purchase of fertilisers and improved cultivars (Lele et al. 1989 cited in Williams et al. 2000). The yield of cotton increased more than six-fold from about 200 kg/ha in the mid 1960s to about 1,300 kg/ha in the mid-1980s. The area under the crop also expanded, creating labour shortages for land cultivation and weeding that were filled through the introduction of animal traction. Follin and Deat (1999) indicated that between 1960 and 1999, the use of animal traction equipment rose from near zero to 50% in Burkina Faso and Côte d'Ivoire and to 90% in Mali. As more animals provided traction, it became feasible to transport manure and fertilisers to more distant and previously unmanured fields. Additional benefits accrued from the transfer of technologies and knowledge acquired from cotton production to traditional staples such as sorghum and pearl millet (Sanders et al. 1996; Giraudy 1999). Also, processing cotton-seed provided readily available protein-rich cotton seed cake and facilitated intensive livestock fattening and dairying operations. It is estimated that when the available cotton seed cake and useable residues from sorghum and maize are combined, the system has an estimated 1,380 million kg DM of useable crop residues capable of maintaining its 1.2 million TLU for a period of 6 months/year (Table 3).

The principal drivers of the cotton–maize–sorghum–livestock production system are the price of cotton in the international market, the level of institutional support and the availability of technologies. Livestock provide traction and a means to transform and add value to the industrial by-products of cotton oil extraction and food–feed crop residues into meat and milk. When cotton prices fell or local organisations, cooperatives etc. would not guarantee prices, and when institutional support slacked in the francophone countries, some cotton farmers reverted to the production of traditional staples.

Groundnut–rice–livestock system

The groundnut–rice–livestock system is found mainly in an area of Senegal known as the *Bassin Arachidier* (groundnut–producing basin). It covers an area of about 27,407 km^2 (1478 km^2 or 5.4% cultivated) and has about one million people and 287,000 TLU composed of 228,000 cattle and 541,000 sheep and goats (Table 2). Average farm size in the area is 7–8 ha.

Fodder from groundnuts and straw from rice provide feed for livestock that are integrated into the system especially in upland areas where groundnut is intercropped with pearl millet and animal traction is used for both cultivation and transport. Useable crop residue within the system has the capacity to sustain its ruminant population of 287,000 TLU for 3.1 months/year (Table 3). Groundnut production is driven by both the commercial value of groundnut oil and the popular food value of groundnut sauce that is eaten as a regular accompaniment for rice in the zone. With market opportunities and population already playing important roles in the system, its future prospects are good, especially with on-going market liberalisation and other reforms of the groundnut marketing sector in Senegal as reported by Badiane et al. (1997).

Cassava–maize–yam–livestock system

Cassava is arguably the most dominant food staple in the humid zone of West Africa extending into the wetter parts of the subhumid zone, from Guinea through Liberia, Côte d'Ivoire, Togo, Benin and Nigeria. The definition of most of the crop–livestock production systems in this area is more in terms of which other crops are found in association with cassava, and the relevance of such crops to subsistence, income and provision of residues for use as livestock feed and mulch. As a result of the various degrees to which the associated crops fulfill the above roles, four crop–livestock production systems involving cassava have been defined. One of them is the cassava–maize–yam–livestock production system.

This system accounts for 136,518 km^2 with 17,540 km^2 or 12.8% cultivated. It has 13.6 million people and about one million TLU consisting of 408,000 cattle and 4.4

million sheep and goats (Tables 2 and 3). It is found in both the wetter subhumid and the humid zones where the presence of tsetse is a major challenge to livestock production. For this reason, the trypanotolerant West African Dwarf sheep and goats and the N'Dama and Keteku breeds of cattle are predominant. Because major cassava-producing areas usually overlap with areas where small ruminant density is higher than cattle density, the use of cassava peels for feeding livestock has been largely restricted to small ruminants. In this system, about 74% of households own goats (average flock size 5.1) compared to about 13% that own sheep (average flock size 1.9) which generally roam free in the post-harvest season and whose feeding is supplemented with household wastes such as cassava, yam and cocoyam peels, and cut-and-carry fodder (Onwuka et al. 1992). According to Smith (1992), small ruminants and other livestock are rarely integrated with crop production implying that crop residues and by-products are not systematically and strategically used for livestock feeding, and the potential of animal waste to improve soil fertility and conservation is not fully exploited.

Among the main crops of West Africa, the highest increases in production in the last two decades have been experienced with tubers. Annual cassava production rose from 16.5–49.6 million t and yam production from 9.3–35.0 million t between 1980 and 2000 (FAO 2003, Figure 4). For cassava in particular, this was accomplished in spite of the challenges from the cassava mealybug, cassava green mite, African cassava mosaic virus and cassava bacterial blight that are the major pests and diseases. Considering that cassava peels make up 20% of the whole tuber and contain 86.5–94.5% DM, and 0.7–1.0% nitrogen (Ifut 1991), there are about 10 million mt of reasonably good quality livestock feed that are also under-exploited due to this disease challenge and a culture that apparently de-emphasises livestock within its agricultural production systems. Maize is also important, especially in the area bordering the subhumid zone, where, because of the availability of moisture, it is possible to grow two crops of maize each year.

Opportunities for exploiting the full potentials of this system lie in sustaining the increasing productivity of tubers, especially cassava, and in integrating crop and livestock production. Disease is a key biological constraint to livestock production.

Cassava–yam–livestock system

This is one of the cassava-based crop–livestock production systems. In this system, cassava and yams predominate while soybean is of emerging importance, especially in Nigeria. The system covers 0.29 million km^2 and stretches across the middle belts of Nigeria and Côte d'Ivoire with fair representation in Ghana, Togo and Benin. It has human and livestock population densities of 49.5 persons/km and 13.7 TLU/km^2 and a cultivation intensity of 13.4%. Crop–livestock integration, especially the use of animal traction, is low.

Production is driven by the demand for food in highly populated coastal areas of the region. Opportunities for improving the system are similar to those of the cassava–maize–yam–livestock system.

Rice–cassava–maize–livestock system

This system is found in patches in the rainforests of Guinea, Sierra Leone, Liberia and Côte d'Ivoire. The system encompasses 0.26 million km^2 and is characterised by low human population density (28.6 persons/km^2), low livestock population density (5.1 TLU/km^2) and a cultivation intensity (3.3%) that is the lowest in the entire region (Table 2). The tsetse challenge is high, restricting livestock reared to trypanotolerant breeds. Useable crop residues from the cleared and cultivated areas have the capacity to sustain all the ruminant livestock within the system for up to 5.8 months/year (Table 3). There seems to be potential for expanding the livestock population in this system to utilise available crop residues more fully.

Coconut–oil palm–fruits–livestock system

This system covers an area of 46581 km^2 (22% cultivated) with 5.1 million people and 0.2 million TLU composed of 79,000 cattle and about one million sheep and goats. Oil palm, coconut palm, citrus trees and pineapples are common (Tables 2 and 3). In 2000, West Africa produced 12.7 million t of oil palm fruits, 0.8 million t of coconuts, 4.0 million t of citrus fruits and 1.3 million t of pineapples (FAO 2003). These crops are of immense economic importance and there is usually huge demand for labour to keep the underbrush in the plantations low. Cover crops such as *Centrosema* and *Pueraria* may be planted to smother the weeds and in addition to control erosion and improve soil fertility. In a study of sheep that were reared in tree crop plantations in Ghana, Fianu et al. (1994) found that plantation sizes ranged from 3 to 16 ha and plantation owners had about 7–58 sheep. Fianu et al. (1994) cited Wilson and Lansbury (1958) as estimating the average annual green herbage yield of cover crops in the plantations at 20.8 t/ha thus pointing to the enormous potential for integrating livestock into tree crop plantations. In spite of the obvious advantages that crop–livestock integration could bring to the system, adoption by farmers has been low. According to Fianu et al. (1994) in some cases this is due to the remoteness of the plantations from town, which exposes the animals to theft and makes their marketing somewhat difficult. In other cases, lack of credit to construct pens and farmsteads within the plantations was another factor limiting the development of livestock in this system.

Among the fruits found in this system, pineapples are currently gaining importance as an export crop. Their cultivated area is expanding and especially between western Ghana and eastern Côte d'Ivoire, oil palm plantations are giving way to pineapple plantations. With this emerging trend, and should local processing of pineapple become popular, then pineapple pulp may become an important livestock feed with enormous potential for reconditioning live animals arriving from the Sahelian countries of the region before slaughter. This system has the capacity to integrate livestock and reduce the cost of labour for weed control and to gain meat, milk and manure in return, as well as to provide ingredients for stall feeding in landless urban and peri-urban livestock production systems.

Cocoa–plantain–cassava–livestock system

The cocoa–plantain–cassava–livestock system covers 0.19 million km^2, has 17.6 million people (94.5 persons/km^2) and the lowest livestock population density (4.4 TLU/km^2 or 586,000 TLU) in the region (Table 1), with the vast majority of livestock being small ruminants. Cocoa, plantains, bananas, cassava, kolanut, citrus and maize are important crops. While plantain is a regional staple, cocoa is major cash crop that contributes significantly to the economies of countries in the region, particularly in Ghana and Nigeria—Ghana being the world's highest producer at one time. In West Africa, 2.2 million t—of cocoa beans and 5.9 million t of plantains were produced in 2000 (FAO 2003). Cocoa production, driven by prices in the world market, declined during the 1980s and early 1990s but picked up again when structural adjustment programmes in the region made its production and export competitive.

The integration of livestock into cocoa plantations is limited by the fact that cocoa is usually planted under shade trees and there is not enough light for herbaceous vegetation to grow and offer opportunity for grazing. However, dried cocoa pods are used in combination with cassava, yam, plantain, cocoyam peels and other household wastes as supplementary feed for small ruminants in homesteads.

Rice–livestock system

The rice–livestock system exists in locations where rice is the predominant crop under the 'irrigated systems' defined by Dixon et al. (2001). These include large riverine and flood recession-based systems that are found in pockets along major rivers, as well as the *fadama* systems. In West Africa, many of these systems occur along the Niger and Gambia rivers and the flood plains around Lake Chad. Within the irrigated systems, Dixon et al. (2001) distinguished between large-scale centrally managed irrigation schemes and small-scale farmer-managed schemes, and noted that irrigated fields almost always constitute part of a larger farming and livelihood system that includes rainfed farming and livestock. The systems described in this section exclude the large-scale centrally managed irrigation schemes such as the Hadejia Jamaare' River Basin Development projects in Kano State, Nigeria, that are defined as high-value vegetables–rice–livestock systems and discussed in another section.

The rice–livestock system has an area of 0.34 million km^2 of which 12.8% is cultivated (Table 2). According to de Leeuw (1997), rice straw from this system becomes available in harvested fields and communal threshing sites about 2 months after the sorghum and pearl millet harvest is completed in the surrounding fields. In the same report, de Leeuw cited Wilson et al. (1998) who found that reliance on rice straw and fields after harvest was very high in the areas surrounding the large irrigation projects along the Niger River in central semi-arid Mali where herds grazed upland savannahs in the rainy season, but from November to May relied on rice straw (57%), pearl millet residues (12%) and harvested rice fields (20%). Within the rice–livestock system there are 15 million people and 4.5 million TLU made up of 3.2 million cattle and 10 million sheep and goats (Table 2). It is estimated that useable rice straw, (6081 million kg DM) contributes 15.7% by weight to total useable crop residues in West Africa and is capable of supporting the 4.5 million TLU in the system for a period of 7.2 months/year (Table 3). Rice is an increasingly important staple in high demand in both rural and urban areas in the region. As such, the region's rapid population growth and urbanisation will continue to drive production in this system. Technologies that enhance productivity are particularly crucial as there are concerns that after rapid growth in the 1970s and 1980s, increases in the yield of rice have been lower than population growth rate in the 1990s and might stagnate. An improvement in the palatability and proportion of useable rice residue presents another opportunity to develop the system further. Before this, however, there is the need for rice breeders to be convinced of the need to assess potential trade-offs between breeding for straw quantity and quality in addition to grain quantity, and if these do not exist or are not considerable, to develop improved food–feed rice genotypes, that seem to be in high demand by farmers. Fodder resources in rice–livestock systems could also be improved through relaying high quality forage after rice has been harvested.

High-value vegetables–rice–livestock system

This system has major locations along the Niger River especially the segment between its entry into Mali and exit from Niger, and the extensive *fadamas* (inland valleys) around Kano, Nigeria. It differs from the irrigated systems in that high-value vegetables such as tomatoes, peppers, onion and carrots are planted and irrigated through the dry season after the rice has been harvested. This is especially so for the Kano irrigation scheme which satisfies a major part of the demand for vegetables in the urban centres of southern Nigeria. Since these vegetables leave no significant residues for livestock production and occupy the land after the rice harvest they limit the grazing period and therefore the useable proportion of the rice straw in the fields. However, in locations where dual-purpose cowpea varieties are planted in preference to vegetables (as is found, for instance, in Bunkure around Kano), there has been a significant increase in dry-season grazing by pastoralists that is associated with the availability of greater quantities of high-quality fodder (Inaizumi et al. 1999).

This system covers an area of 91,270 km^2 with 5 million persons and 1.3 million TLU. Its cultivation intensity (19.4%) is among the highest in the region (Table 2). Vegetables, rice and small quantities of wheat and sugarcane are grown in the very low-lying areas. Sorghum and cowpea are important crops on the slightly elevated portions of the land. There is considerable pressure on land within the irrigation scheme and the majority of the small-scale farmers have less than 1 ha to cultivate (Inaizumi et al. 1999). However, including other landholdings and resources outside the scheme area, an average household has about 6.5 ha of farmland and owns 9.3 TLU. About 19% of the farmers use work bulls for cultivation, compared to the average of 53% in the northern Guinea savannah and semi-arid zones (Okike 2002b). Such low use of animal traction is explained in part by the fragmentation of plots and difficulties (including the risks of crop destruction and conflict) associated with getting animals and traction equipment to deep-lying plots across the flow channels. Even though the intensive nature of the production system requires higher labour input, complementing human labour with animal traction is more difficult than in the cotton–maize–sorghum–livestock production system where the ease of substitution led to tremendous expansion in cropped areas.

According to Dixon et al. (2001), the future potential for intensification of this system is good, if water shortages and irrigation scheme breakdowns can be avoided and input/output price ratios do not deteriorate. Improving infrastructure will cut down on the time spent between harvest and reaching the final product and the associated deterioration in product quality. Better access to market information will also benefit the system.

Landless, stall-feeding, intensive urban and peri-urban livestock system

In West Africa, stall-feeding is a common and long-standing tradition, probably rooted in fattening of sheep specifically for the *Tabaski* Muslim festival. In West Africa, stall-feeding is not restricted to 'landless' systems in urban and peri-urban locations, but it is also practised in most mixed systems. In major livestock markets across the region, it is also common to find some livestock traders that purchase lean animals to fatten and resell them in the same market. This may be a part-time routine activity or periodic and targeted at specific occasions. The boundaries of the stall-fed (landless)/urban and peri-urban livestock system are defined on the basis of sites in the region with human population density greater than 450 persons/km^2, irrespective of whether city lights show up at those locations at night or not. This obviously omits stall feeding in rural areas and does not capture fattening in major livestock markets, except where such markets fall within the defined population density.

This system covers an area of 52,642 km^2, although in terms of spread, it is the most fragmented. It is found in all agro-ecological zones and in almost all other production systems identified in this paper (Plate 12). About 55 million persons or more than a quarter of the people in West Africa live in areas defined by this system at a mean density of more than 1000 persons/km. Average livestock density within the system (14.6 TLU/km^2) is above the regional average and cultivation intensity (24.4%) is among the highest (Table 2). A characteristic of the system is that it embodies the final stages in the evolution of crop–livestock production systems ranging from feed-constrained crop–livestock integration in peri-urban areas to specialised crop (horticulture) and livestock production in the urban centres. Due to the high cultivation intensity in peri-urban areas, feed is scarce, not only during the dry season but also during the planting season since as there are very few, if any, fallow plots and livestock can hardly reach them without the risk of destroying crops and causing conflict. In urban centres, all feed-crop residues, cut-and-carry fodder and other supplementary feed—are imported from outside the stall. Crop and livestock production are therefore spatially separated, which limits the extent to which the usual benefit of crop–livestock interaction can accrue to its practitioners.

An important feature of stall-feeding systems is that the livestock ration depends on the surrounding crop–livestock system. For instance, a landless system located in Niamey, Niger, is likely to be based on feeds supplied by the pearl millet–cowpea–livestock system, while a landless system in Dakar, Senegal, is likely to be based on feeds provided by the characteristics of the rice–groundnut–livestock system. The types of breeds used in stall-feeding systems are also defined by the predominant breeds in the crop–livestock systems that exist in their surroundings.

With the current trends in urbanisation, this system is expected to grow in importance and to encourage its practitioners to grow their own feed to ensure a reliable source of nutrition for their livestock. Issues of sanitation, and public and environmental health will come to the forefront, especially with the expansion of the more market-oriented aspects of the system that are less integrated into crop farming.

Evolution of livestock and crop–livestock systems in West Africa and opportunities for development

In West Africa, as in sub-Saharan Africa, there is wide diversity of livestock systems. The path and rate at which these systems evolve are largely dependent upon the interaction of agro-ecological, social, economic, technological and institutional factors. McIntire et al. (1992) proposed that first of all, agro-ecology and, secondly, population density are the principal factors that create and drive the diversity of agricultural systems, after which market access, land forms, and incomes, among other factors, begin to exert significant influences. Boserup (1965; 1981) argued that as population pressure leads to smaller landholdings, it also induces agricultural intensification.

Although agro-climatic and demographic conditions may be the primary drivers of the evolution of agricultural systems, the introduction of appropriate technologies, institutional support, policy reforms and other socio-economic factors play key and important roles (Gabre-Madhin and Haggblade 2001). For instance in the cotton–sorghum–maize–livestock system, cotton production was promoted through the provision of such inputs as new cotton varieties, fertilisers, insecticides, animal traction equipment, activities of farmers' groups and extension support. Between 1960 and 1999 these efforts resulted in quadrupled cotton yields and the use of animal traction equipment rose from near zero to 50% in Burkina Faso and Côte d'Ivoire and to 90% in Mali and Cameroon (Follin and Deat 1999) with additional benefits from the important residual effects of cotton fertiliser on cereal production (Giraudy 1999). Rice production in West Africa was also boosted through policy reforms in Malian rice markets (Diarra et al. 2000) and breeding of interspecific hybrids (WARDA 2001). Likewise, in the case of maize, West Africa achieved the fastest rate of production growth in Africa, with annual increases of 4.5% between 1975 and 1999 (Byerlee and Eicher 1997). This evidence points to the need for understanding the forces that drive the evolution of livestock systems if appropriate policy, institutional and technical innovations are to be designed.

An in-depth analysis of the evolution and opportunities for development of each and all of the 15 livestock systems identified in West Africa is outside the scope of this paper. However, to illustrate the potential application of the proposed typology, a summary of the main features of the 15 systems in terms of the role of livestock, role of crops, principal driving forces, main sources and types of risk and key opportunities for development is presented in Table 4. On the basis of similarity in these features, the systems were regrouped into six.

In pastoral systems, found mostly in the arid and drier semi-arid zones of the region, where a high risk of crop failure exists, there is a comparative advantage for livestock production. Because of high herd mobility this system is well adapted to the unpredictable weather and the risk associated with the constant threat of drought. The primary role of livestock is to serve as an asset for risk management in addition to its traditional role of providing savings. Technologies for water and soil nutrient management that increase the chances of successful crop production would modify the role of livestock to include the provision of manure for crop production. As cropping activities increase herd mobility may be affected, although this may be compensated by the increased quantities of crop residues that become available within the system.

In the wetter zones, where crop–livestock systems thrive, the principal driving forces are population pressure, urbanisation and its associated rising incomes, and changing consumption patterns that improve market opportunities for agricultural produce. In the cereal–legume dominated systems, livestock supply manure, milk, traction and cash, while crops are grown for subsistence and for cash, in addition to supplying

Table 4. *Main features, evolution and development opportunities of major livestock systems in West Africa.*

Production systems	Characteristics, determinants, constraints, and opportunities for development				
	Role of livestock	Role of crops	Principal driving force	Main sources or types of risk	Opportunities for system's development
Pastoral	Food (milk), risk management, savings, manure for exchange	Limited residues for feed (if grown)	Comparative livestock production advantage, ready market for animals in other zones	Weather – especially risk of drought, contracting grazing land, conflicts	Early drought warning, facilitate herd mobility, offtake of weaned calves, conflict resolution
Pearl millet–cowpea–livestock Pearl millet–groundnut–livestock Sorghum–maize–cowpea–livestock Maize–sorghum–livestock Groundnut–rice–livestock Rice–livestock High-value vegetables–rice–livestock	Manure, food, cash, traction	Subsistence, cash, residues for livestock feed	Population pressure, urbanisation, rising incomes, good market opportunities, comparative crop production advantage	Price, financial	Facilitate access to markets, provide technologies to enhance productivity
Cotton–maize–sorghum–livestock	Traction, manure, food, cash	Cash, subsistence, feed	Use of improved technologies for cash-crop production	Price, financial	Support services, market information
Rice–cassava–maize–livestock Yam–cassava–maize–livestock Cassava–yam–livestock	Savings, food	Subsistence, cash, residues serve mainly as compost	Urbanisation, market access, potential for crop production	Price, financial, animal health risks	Reduce animal health risk to enhance crop–livestock integration
Cocoa–plantain–cassava–livestock Coconut–oil palm–fruits–livestock	Value-added maintenance of undergrowth, cash	Cash, subsistence	Urbanisation, shortage of plantation labour	Price, financial	Technologies for feeding and preserving emerging feed sources e.g. pineapple pulp
Stall-feeding intensive urban and peri-urban livestock	Cash, food (meat, milk)	Cash, subsistence, feed (if grown)	Festival fattening, urbanisation	Price, diseases of intensification and crowding	Facilitate access to markets, provide microfinancing support

residues for feeding livestock. These systems, found mostly in the wetter semi-arid and drier subhumid zones, bring to the fore the important influences of factors other than agro-ecological potential in the evolution of crop–livestock systems. Williams et al. (2000) cited examples of how the same semi-arid climate in Niger that supports only partial intensification of crop–livestock systems in the south-west supports intensive and quite successful onion and garlic production in the inland valleys of central Niger, and how intensive production still takes place in the groundnut basin of Senegal in spite of the poor soils. These examples demonstrate the interacting effects of agro-ecological, economic, technological and institutional factors in determining the pathway of intensification at each location.

The tuber–livestock and tree crop–livestock systems are under-stocked compared to the cereal–legume–livestock systems. These differences reflect not only the production environment (e.g. the level of disease challenge is lower in the cereal–legume zone than in the tuber belt) but also the feed value of the residues produced in those systems. In the case of rice-based systems, because of the poor feed quality of rice straw, livestock feeding depends on the inclusion of other forages, which allows for crop diversification. Considering that the estimates of useable residues applied in this paper have been based on 33% for pearl millet, sorghum and maize stovers and rice straw and 67% for cowpea and groundnut haulms, it is clear that even at current production levels, there is an enormous potential for crop residues within crop–livestock systems to provide feed for livestock that is yet to be harnessed. This is one of the major challenges to increasing the productivity of crop–livestock systems and improving the livelihood of the poor smallholder farmers within them.

Finally, within each system, specific opportunities for development will depend on the diversity of the population of producers. Wiggins and Proctor (2001) discussed the implications of this diversity for rural development and proposed a framework in which specific opportunities for development are determined by their proximity to urban areas (access to markets) and the quality of natural resource endowment (productive potential). For instance, in peri-urban areas with good access to markets and substantial non-farm income, the opportunities would likely be for small-scale, high-value crop and livestock products, whereas in remote areas with poor natural resources the main opportunities would rely on low productivity and subsistence farming.

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