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Farming and cropping systems in the West African Sudanian Savanna

WASCAL research area: Northern Ghana, Southwest Burkina Faso and Northern Benin

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Acronyms and Abbreviations

BD	Bulk density
CARDER	Centre d’Action Régionale pour le Développement Rural (Benin)
CEC	Cation Exchange Capacity
CIRAD	Centre de Cooperation International en Recherche Agronomique pour le Développement (France)
DGPER	Direction Générale de la Promotion de l'économie Rurale (Burkina Faso)
FAO	Food and Agriculture Organization
GEF	Global Environment Facility
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IMPETUS	An Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa
INRAB	Institut National des Recherches Agricoles (Benin)
ITCZ	Inter Tropical Convergence Zone
Ks	Saturated hydraulic conductivity
LER	Land Equivalent Ratio
MAHRH	Ministère de l’Agriculture de l’Hydraulique et des Ressources Halieutiques (Burkina Faso)
MAHRH	Ministère de l’Agriculture de l’Hidraulique et des resources Halieutiques (Burkina Faso)
SARI	Savanna Agricultural Research Institute (Ghana)
SD	Standard Deviation
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
UER	Upper East Region
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization

Abstract

Ecological fragility combined with institutional weakness and political and economic instability make West Africa one of the most vulnerable regions to climate change. The West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) tackles this vulnerability by investigating the interface of climate and rural social-ecological systems, in order to propose *ad hoc* adaptation measures. In this context, the characterization of the livelihoods of rural communities is crucial since these constitute the units of evaluation and analysis of ongoing and forthcoming studies. Purposefully, this paper provides a joint description of these livelihoods. Divided in three sections, the first one focuses on the agroecological (biophysical) characteristics, detailing climatic, edaphological and hydrological qualities mainly; the second section, portrays the principal socioeconomic features: demography, culture, and organizational and economic institutions; and the third section, describes the main farming and cropping systems themselves, matching the first sections outcomes with managerial aspects, such as farming practices and regional variations, planting patterns, etc. The paper concludes with an overview on relevant features of the farming and cropping systems, recalling the main limiting factors and the local strategies used to overcome them.

Keywords: climate change, West Africa, cropping systems, farming systems, vulnerability

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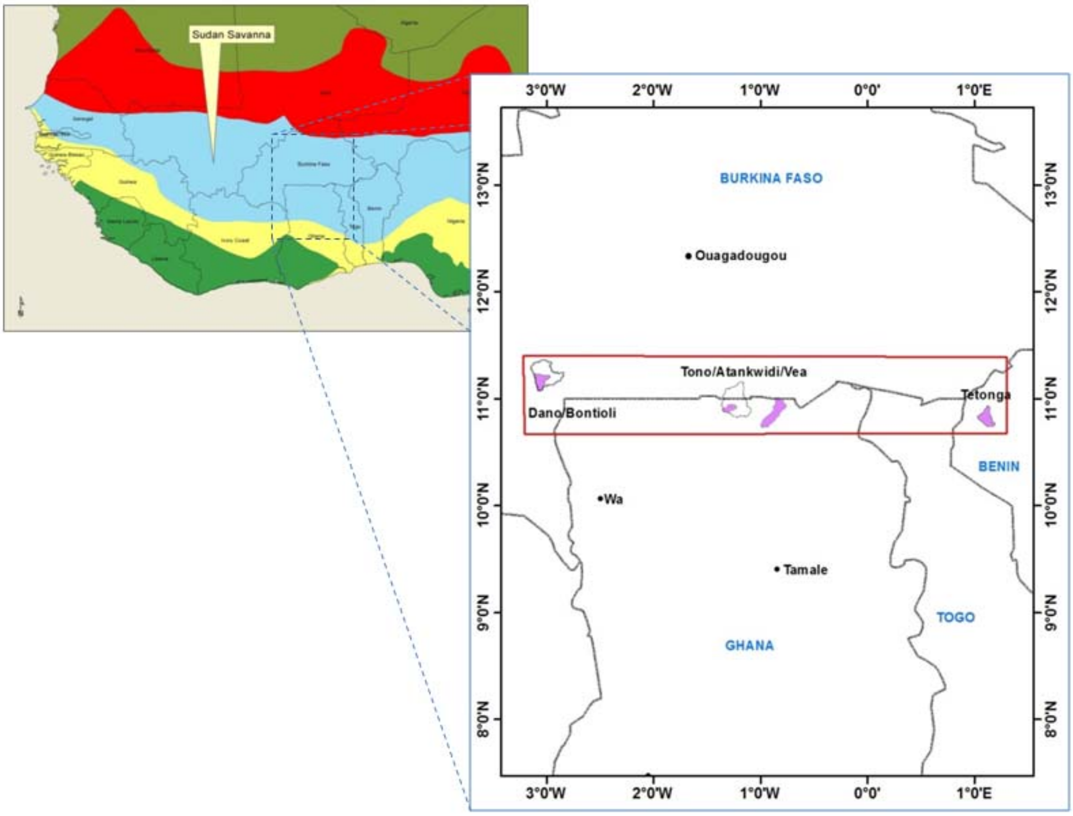
1 Introduction

1.1 West African agriculture, geographic and climatic determinants

West Africa is considered one of the regions to be most affected by climate change. Land degradation, increasing discrepancy between water demand supply and as a consequence, declining agricultural productivity, and subsequent changes in livelihoods are expected to occur in the rural areas.

The regional vulnerability of West Africa is highly correlated with its climatic and geographical peculiarities. From the Atlantic Ocean shore northwards, a climatic variation has determined a diversity of biogeographical zones from south to north: rain forest, forest-savanna ecotone, savanna, Sahel and desert[1] (Figure 1).

Figure 1: West African Savanna subzones and the WASCAL research sites



[1] In the **rain forest** zone near the southern Atlantic coast, the landscape is mostly flat with remnants of dense humid forests, with annual rainfall higher than 1500 mm distributed in a bimodal pattern. Agriculture focuses on tree crops, e.g., cocoa (*Theobroma cacao)*, palm (*Elais guineense*) plantain (*Musa paradisiaca*), coconut (*Cocus nucifera*) and tubers; livestock plays a minor role. The population is dense due to the concentration of major economic opportunities. The **forest-savanna ecotone** shows a bimodal rainfall pattern between 1300 and 1500 mm/year and variable altitudes. The landscape is dominated by an irregular mosaic of forest and savanna species. Farming focuses on seasonal food crops and vegetables, perennial tree species and livestock, determined more by its inhabitants' cultural set (migrants from the north and south) than by the ecological conditions. The **savanna** is dominated by grassland and trees with low density, it is warmer than the rain forest, and has a monomodal rainfall season with 600 to 1500 mm/year alternated with pronounced dry seasons. Agriculture focuses on grain crops and livestock production. The limited availability of water and nutrients makes the region highly fragile and prone to poverty. The **sahel** is composed of semi-arid grasslands, savanna, steppes and thorn shrublands; it is flat (200-400 m a.s.l.), with rainfall from 200 to 600 mm/year in a unimodal pattern; droughts and dust storms are frequent, and major constraints are overgrazing, overpopulation, and soil erosion and desertification. Its economy is based on livestock production through transhumant shepherding. The **desert** is flat, with little vegetation, and the climate is hyper-arid, with cumulated rainfall of less than 100 mm/year. There are no agricultural activities.

In the coastal countries, e.g., Benin Republic, Ghana, Togo and Ivory Coast, the development gradient corresponds to the geographical one. The coastal-southern regions present more favorable ecological conditions for agriculture, and here most economic and trade opportunities exist. It is argued that although this difference is long-dated, it has later intensified during the colonial period and the increased dependence of maritime commerce.

The savanna landscape covers more than 12 million km^2 (about 60% of tropical Africa) and includes 45 countries. Its bioclimatic gradient can be divided in subsets depending on annual rainfall amount and distribution and length of growing season, i.e., Guinea (sub-humid) savanna and Sudanian (semi-arid) savanna. The former more humid with 900-1200 mm rainfall per year and 140-190 growing days; while the latter is drier with 600-900 mm rainfall per year and 90-140 growing days (Ker 1995).

Much of the Sudanian savanna landscape has been shaped by human activities; areas with natural flora have been converted into other land uses and the fauna has been depleted by intensive hunting. However, few small forest patches remain as sacred groves where part of the original biodiversity is conserved (Laube 2007).

Triggered by demographic changes, West African farming systems have evolved from the interaction of indigenous migratory systems to sedentary systems based on exotic crop species in diverse arrangements, in accordance with the environmental and socio-economic circumstances of the farmers (Gyassi and Uitto 1997). In the savanna region, the 'cereal-root crop mixed' cropping systems predominate, based on a combination of cereals, leguminous and root crop species (Hall et al. 2001). Cotton, sugar cane and rice are common if appropriate institutional and ecological conditions exist (Lang and Cantrell 1984, Reddy et al. 1992). Livestock presence is minor (Reddy et al. 1992).

The agricultural potential of the Sudanian savanna has been largely acknowledged, but also limiting factors identified. The insufficient moisture due to high rainfall variability and frequent droughts (Challinor et al. 2007) together with the poor soil fertility (Sanchez 2002) are considered the main ecological constraints, in addition to the poor farmers' technical, managerial and financial capabilities (Roth and Sanders 1984, Dvorak 1993) and the general structural, economic and institutional weakness (The World Bank 2009, Future Agricultures 2010) in Sub-Saharan Africa.

1.2 The West African Science Service Center on Climate Change and Adapted Land Use (WASCAL)

In this context, the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL), as a German-West African initiative to generate expert knowledge, improve analytical power, and form human resources to face the current and forthcoming challenges deriving from climate change is proposed.

Through its Core Research Program (CRP), WASCAL develops cutting edge research in relevant aspects of the social-ecological systems affected. Agricultural land use systems are one of these, since they involve most of the population, and farming is the most important economic activity in the region.

In this working paper, the general characteristics of the predominant farming systems of the Sudanian savanna zone are summarized. The major features of the rural livelihoods of the WASCAL CRP intervention zone are described in three sections: (1) agroecological profile, (2) socio-economic profile, and (3) farming and cropping systems.

Most references were derived from scientific literature and recentness was prioritized. Participation of experts, both from Germany and West Africa, was required to validate the literature review, and to some extent to complement it. However, the data review is far from being exhaustive. The large area to be covered and insufficient data sources were major limiting factors.

This working paper was prepared in the framework of the working package 3.1 ‘Climate and technology impact on the provision of food, feed and fiber from agroecosystems’. It is a kick-off document on the existing farming and cropping systems. However, it could also contribute a first insight into the social-ecological systems in the WASCAL working area, which could be useful for other working packages.

The structure of the paper follows a top-down approach, where general assertions are made at the beginning of the section and later on explained based on regional examples from the three major areas of attention, i.e., northern Ghana, south-western Burkina Faso and north-western Benin (Figure 1).

2 Agro-Ecological Profile

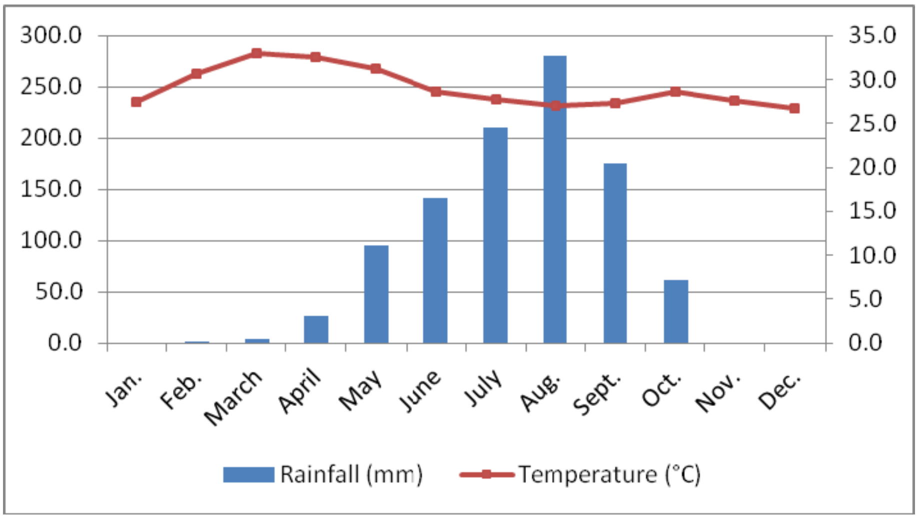
2.1 Climate

In general, the West African climate is governed by the Inter Tropical Convergence Zone (ITCZ) determined by the African monsoon[2] (GEF-UNEP 2002) that produces two annual air masses oscillations: (a) the 'monsoon' from south (equatorial Atlantic) to north (Sahara desert) causing moist conditions in the north through a unimodal rainy season between May and October reaching its maximum in July and August, and (b) the 'northeast trade' wind from north to south occurring between October and April, a cold and dusty wind bringing rainfall to the south and leaving the north dry and hot; the influence of this period is known as *Harmattan* (Badini et al. 1997, Ouédraogo 2004, Kpongor 2007, Kanchebe 2010).

2.1.1 Temperatures

By its tropical location and geomorphology, incoming solar radiation is relatively constant as are the temperatures. In the southern Sudanian savanna, a night-day variation of 20°C is usual (Bagayoko 2006, Schindler 2009) (Figure 2), but northwards in central Burkina Faso and near the Sahel, average temperatures of 25°C in January and 32°C in April and relative humidity of 6% during the dry season and 95% in the rainy season are common. Moreover, temperatures can oscillate strongly, from 15°C during the night to more than 40°C during the day (Sandwidi 2007). Recent observations have found a rise in the average temperature of 1°C between 1960 and 1990 (Ouédraogo 2004, Sandwidi 2007).

Figure 2: Average monthly temperature and rainfall in Bawku, Upper East Region, Ghana (1993-2011) (SARI 2011)



2.1.2 Hydrology and rainfall

In general the region is poor in water resources. The main constraints are the distance to the sea, the monomodal rainfall regime (Figure 2), and groundwater table of crystalline rock with poor aquifer conditions, therefore groundwater levels vary greatly. In the Atankwidi basin in the Upper East Region (UER) in Ghana, variations between 1 m and 29 m have been reported, which strongly influence the farmers' irrigation strategies in the dry season (Schindler 2009). Similarly, in south-

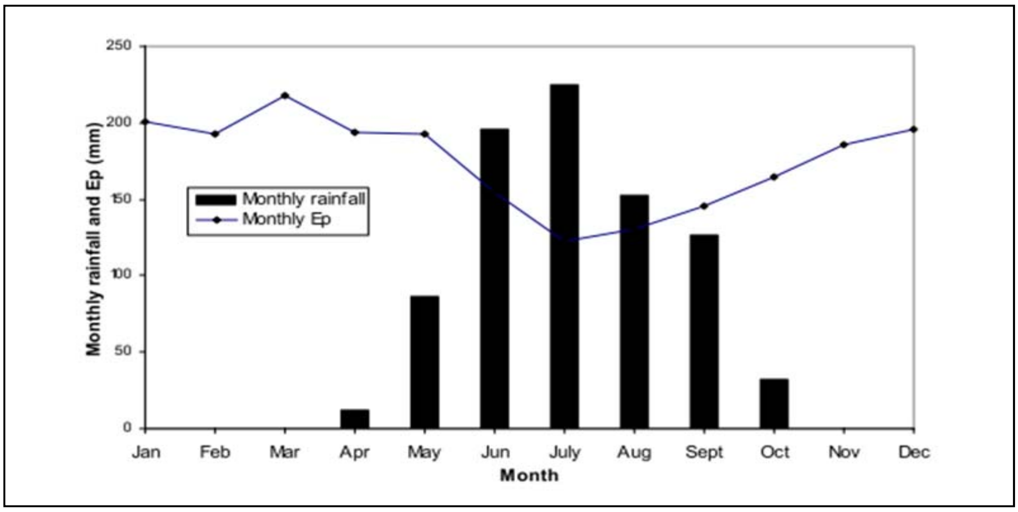
[2] Monsoon (from Arabic *mawsim* = season) is a seasonal reversing wind that leads to changes in precipitation. The monsoon, due to the difference in thermal capacities between ocean and continental masses, provokes a humid, hot wind from the sea to the land that condensates due to cooler conditions on the land surface (sometimes highlands) as precipitation. In winter, the process is inverted, and winds blow from the land to the ocean.

eastern Burkina Faso the groundwater table reduces on average 0.6 mm per day in the cropping season, thus the water withdrawal (76 l per capita per day (l/c/d)) greatly exceeds the provision (20 l/c/d), and according to the calculated recharge capacity of the aquifers (2% per year), the projected demand will overtake the supply in 2030 (Sandwidi 2007).

Rainfall follows an decreasing gradient from the south to the north. In the UER, Ghana the monomodal rainfall regime of 3 to 5 months is from April to October, with between 900 and 1000 mm; the remaining seven months are dry (Kpongor 2007, Sanwidi 2007). The onset of the rainy season is generally stormy, but the effective rainfall for agriculture is low, especially due to the high run-off and evaporation. The latter can be excerbated through the Harmattan (Ouédraogo 2004, Yilma 2006, Kpongor 2007) (Figure 2). Recurrent dry spells are also observed, which are especially harmful during the planting season (June and July), as well as recurrent droughts (Sanwidi 2007).

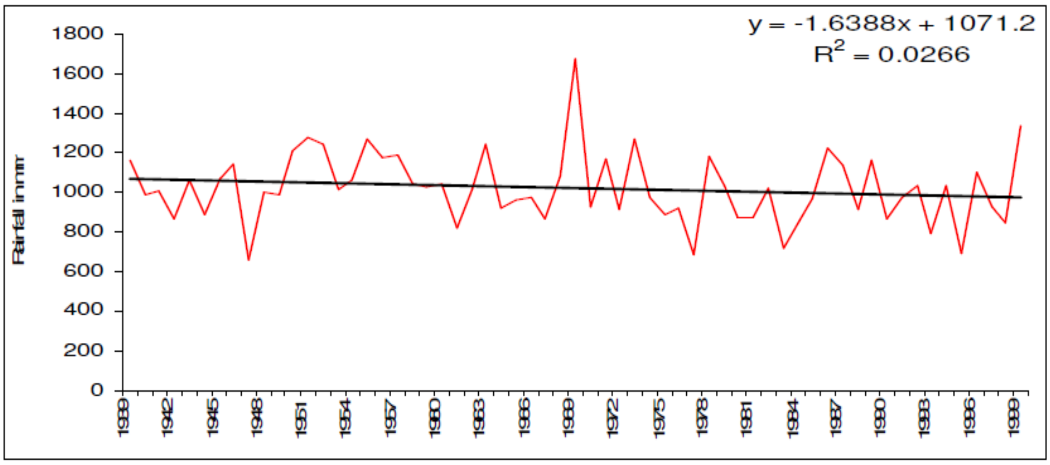
In Burkina Faso, annual rainfall ranges from 400 to 1100 mm from north to south with high spatial and temporal variability. For instance, in the Kompiega basin in south-eastern Burkina Faso, average rainfall 1959-2005 reaches 830 mm/year. In general, evaporation exceeds rainfall except during the rainy season when the basin is recharged (Ouédraogo 2004, Bagayoko 2006, Sandwidi 2007) (Figure 3).

Figure 3: Monthly rainfall and evaporation in Tanyele, Kompienga, Burkina Faso (2004-2005) (Sandwidi 2007)



The high rainfall variability is remarkable. In the Volta basin, the average rainfall between 1939 and 1963 varied from 600 to 1025 mm/year with a coefficient of intra seasonal variation of 7% from the mean, or even interannual variabilities of 20 to 30% what makes prediction inconsistent (Yilma 2006, Kpongor 2007) (Figure 4). In general, a declining in the rainfall trend in northern Ghana can be observed based on the records of 1962 to 1991 compared to 1932 to 1961 (Kranjac-Brisavljevic and Blench 1999 cited by Laube, 2007). Similarly, rainfall intensity is also an issue in the region, since rain events of 120-160 mm/hour are not uncommon (Kowal and Kassam 1978), and it is accepted that rain events of more than 20 mm/hour are highly erosive and lead to higher surface runoff and lower recharge of groundwater.

Figure 4: Rainfall variation between 1940 and 1999 (Yilma 2006)



Studies of the Global Change and the Hydrological Cycle in the Volta basin (Glowa Volta Project) have confirmed climate change effects in the region and warn about related risks, mostly in connection with extreme climatic events (Kunstmann and Jung 2005).

2.1.3 Climate variability and extreme events

As shown above, rainfall variability is the single most important vulnerability-imposing climatic factor. In the Kasena-Nankane district, northern Ghana, these fluctuations provoke stunting, drying up and destruction of plantations.

Especially dramatic were the drought events in the early 1970s in Burkina Faso, whose impacts were worsened by the weak institutional situation after independence; the droughts in northern Ghana 1981 and 1984 and the consequent famines and outmigration (Yaro 2004); or the dry spell in May 2007 which badly affected the early millet yields and the heavy rainfall events and floods in August and September that destroyed late crops such as sorghum, rice and groundnut (Kanchebe 2010).

As climatic factors show high instability, several studies have identified sets of measures that need to be implemented to minimize those risks: improvement of irrigation efficiency, encourage the use of groundwater and promotion of community-based water management (Braimoh 2004, Eguavoen 2008, Sandwidi 2007). In addition, there need to be changes in farming practices, such as shifting of cultivation timing and proper soil preparation, simultaneous cultivation of multiple plots, preference for drought-resistant species, multi-cropping, and traditional manure management practices (Tripp 1982, Kanchebe 2010). Besides crop production, other farming and off-farming activities, like small animals catering, food processing, commerce and temporary migration are less vulnerable to changes in precipitation (Yilma 2006, Awo 2010, Kanchebe 2010, Schravem 2010). Government/ institutional measures such as establishing an efficient irrigation infrastructure and facilitating credit access may reduce the vulnerability of the farmers (Schindler 2009).

2.2 Soils

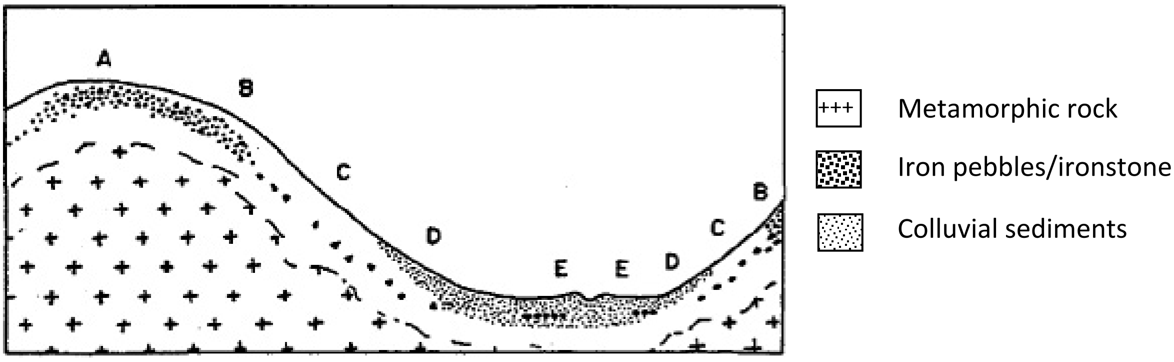
2.2.1 Geology and relief

The region lies predominantly on a Paleoproterozoic granitoid formation and varied Neoproterozoic and Cenozoic layers in different locations (Sandwidi 2007). It is mostly flat (the altitude of Burkina Faso varies from 250 to 300 m a.s.l.) with slight depressions known as 'inland valleys' where water discharges into larger water bodies (Sandwidi 2007).

North-east Ghana is also gently rolling and undulating (slopes rarely exceed 4%). Four major terrain units have been identified: (a) denudated rocky areas, (b) iron-capped hills and remnants, (c) stream beds and (d) valley slopes (Decker 1996 cit. by Kpongor 2007). These are typical constituents of the African 'rolling' geomorphology, which is an influential element with respect to soil properties and has implications for agricultural use. A schematic profile depicts well drained upland soils (red-brown) in some cases with rock outcrops, which turn clayey (yellow-brown) on the middle slope. At the footslopes, sandy loam and loamy sand colluviums (grayish colored) are formed from soil material eroded upslope. In the bottom of the valleys, these colluvial sediments are influenced by a perched or permanent groundwater table where soils with temporarily or permanently poor drainage are formed (Figure 5).

In the UER, three main rock types predominate: granitic, dipping metamorphosed sediments and volcanic material (Kpongor 2007). The derived soils consist of light topsoils with variable texture and coarse sandy loams to heavier subsoils with varying amount of gravel (Kpongor 2007).

Figure 5: African rolling geomorphology (A= hill crest, B= upper slope, C= middle slope, D = footslope, E=valley bottom) (Ker 1995, modified)



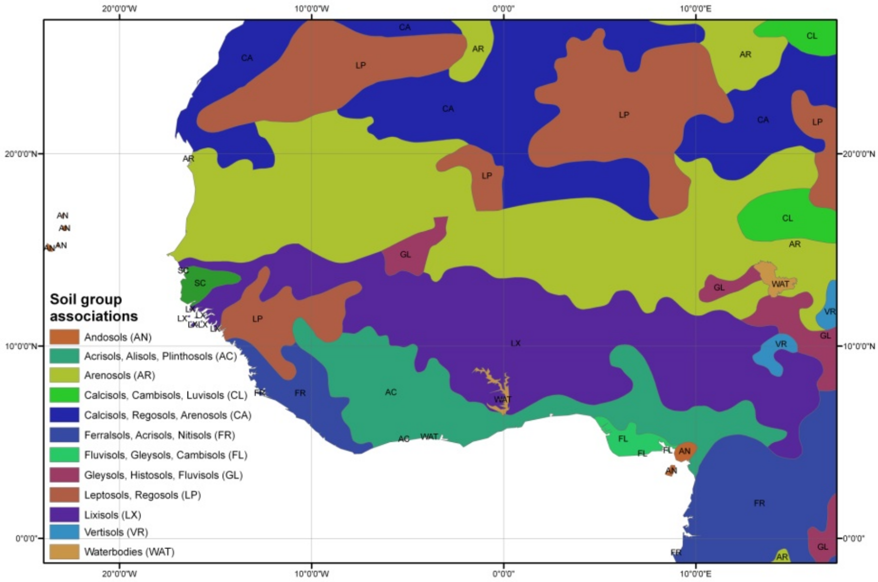
2.2.2 *Main soil characteristics*

Soils in the savanna developed on acidic metamorphic rocks have low activity kaolinitic clay, coarse textured topsoils, low water holding capacities and, depending on the cultivation history, low levels of organic matter, a low supply of nitrogen (N) and phosphor (P) and sometimes phosphate (K), sulfur (S) and zinc (Zn). In addition, they are very susceptible to erosion and compaction. Soil texture in the top layer is mainly sandy (>80% sand), which is due to the loss of dispersable clay through erosion or leaching to the subsoil (Senayah et al. 2005). A number of soils with high clay content occur either in valley bottoms or in alluvial plains or in deeper horizons; the change in texture from the top to the subsoil provokes waterlogging (especially after heavy rains), surface run-off and restriction of the root growth (Jones 1987).

According to the USDA taxonomy, most soils in the region are Alfisols (with argillic or kandic horizon) or Ultisols, i.e., soils with increasing clay content from the top- to the subsoil.

Based on the FAO/UNESCO soil classification system, slightly acid soils with sandy to loamy topsoils and increasing clay content in the subsoil (Lixisols, Acrisols and Luvisols) occur in the sub-humid savanna zone of West Africa (Figure 6), whereas in the semi-arid Sahel acid to highly acid Arensols developed from sand dunes or sand cover dominate. Towards the more humid areas on the coastal belt, highly weathered Acrisols, Alisols, Plinthososl or Ferralsols with low base saturation are increasingly important. The crystalline basement is mainly characterized by Acrisols and Lixisols. In the mountaineous areas (Guinea and southeast Mali) shallow soils (Leptosols) are widespread.

Figure 6: Soil associations with dominant soil groups across Western Africa (according to FAO/AGL 2003)



In the Atankwidi basin (UER, Ghana), six soil associations have been identified, which are composed of three FAO soil types: Lixisols, Leptosols and Luvisols, developed over granites, sandstones and Precambrian basement rocks, respectively. These give origin mainly to light topsoils varying in texture from sands to loams, and subsoils varying from coarse sandy loams to clay with a variable amount of gravel. In valley bottoms, there are heavier topsoils and subsoils.

2.2.3 Soil hydrological properties

As climate changes from sub-humid in the south to semi-arid in the north, water supply to the crops becomes more important as a limiting factor of crop growth and yield. Seasonal distribution of rainfall becomes more concentrated in a few months per year, and the frequency of droughts increases (Challinor et al. 2007). Soils are on average sandy loams with a high sand content of more than 70%, due to the parental material (granitic rock) and erosion or leaching of clay. In combination with low organic matter content, they have therefore a high water infiltration and low water-holding capacity in the top layers. If the subsoil is gravelly and/or with low clay content, then leaching is high during the rainy season due to intense and concentrated periods of rainfall (Schindler 2009). This causes nutrient loss and accelerates soil acidification. If the subsoil is of clay texture, then water logging occurs in the soil profile, causing temporary oxygen stress to crops and risk of surface run-off and erosion.

2.2.4 Nutrient availability

Soils on croplands are poor in organic matter, due to burning of biomass in the prevailing-slash-and burn systems and high temperatures that lead to a rapid decomposition of organic matter (Yilma, 2006). In combination with low organic inputs during the cropping period, the annual burning of vegetation and crop residues and the export to other sites (homesteads), cropping leads to a continuous decline in soil organic matter (SOM) content. Low SOM is associated with low fertility through low reserves of N and P and low cation exchange capacity (CEC) (Table 1). To remediate the poor content of organic matter, the application of organic and inorganic fertilizers and the construction of water conservation infrastructure to avoid run-off and erosion is suggested (Yilma 2006). However, the availability of organic fertilizers in the Sudanian savanna is low.

Table 1: Parameters of topsoil layers of five different land use types in Navrongo, Upper East Region, Ghana (n=150)

Parameter	Topsoil (0-15 cm)				Subsoil (15-30 cm)			
	Mean	Max	Min	CV (%)	Mean	Max	Min	CV (%)
pH	5.46	8.12	4.48	10	5.46	8.38	4.59	13
SOC (mg/ g)	4.0	11.6	0.7	56	0.27	1.32	0.07	56
Nitrogen (mg/g)	0.61	11.0	0.11	245	0.02	0.12	0.01	61
$P_{available}$ (mg/kg)	6.32	44.2	0.93	89	5.9	31.4	1.1	65
$K_{available}$ (mg/kg)	73.6	230	8.22	52	71.5	165	29.1	35
CEC cmol(+)/kg	4.94	21.4	1.51	60	6.30	35.2	2.05	67
Sand (%)	70.9	91.7	18.1	17	64.9	92.4	23.0	20
Silt (%)	24.3	63.6	3.5	36	24.0	63.0	0.2	42
Clay (%)	6.9	32.0	1.2	58	11.1	34.0	0.9	55
BD (g/cm^3)	1.63	1.78	1.40	5	1.67	1.93	1.36	5
Ks (cm/day)	23	363	0.3	227	25	487	0.03	296

Source: Kpongor 2007

Currently, replenishment of soil N comes mostly from biological fixation by leguminous crop species used in traditional systems or in some woody fallow species (Greenland 1985). Phosphorus is considered the main limiting production nutrient in the drier savanna (Sanchez 1976, Kowal and Kassam 1978). Although total P content can be relatively high, if soils have clayey textured subsoil or iron mottles, the plant available fraction is usually low compared to that in soils in temperate zones.

Although its deficiency has been reported in some crops, potassium (K) does not seem to be a limiting factor in soils developed on granitic rocks (Nye and Greenland 1960). However, deficiencies of some micronutrients, as well as of calcium (Ca) and magnesium (Mg), were identified as limiting factors depending on soil parent material, soil type and land use history (Ker 1995). Usually, CEC is low at about 4 meq/100 g, and base saturation is at least 35%; however, the soils tend to acidify when they are heavily cultivated (Sanchez 1976).

In summary, low contents of N and P are critical for crop production, especially if accompanied by low CEC but adequate K levels. Schindler (2009) identified soil fertility and soil texture as determinant soils attributes for her agent-based analysis. Kpongor (2007) insists that application of inorganic fertilizer is a must to improve the depleted savanna soils, but should be combined with organic amendments, otherwise the applied nutrients are at risk of being easily leached due to the sandy nature of the soils (Kpongor 2007).

Thus, it can be concluded that two major natural drivers influence agricultural production in the region: (1) climate conditions with frequent and unpredictable periods of water shortage, and (2) inherent low soil fertility. This situation is aggravated by the fact that 40% of agricultural lands are already affected by human-induced degradation (Oldemann et al. 1991, Zougmoré 2003).

3 Socio-Economic Profile

In a description of a village in Burkina Faso's central plateau it is stated:

> « (…) the farmers are clearly oriented toward subsistence. Their sales are strictly residual, prompted only by 'urgent need', regardless of the market price. If, as harvest approaches, stocks are adequate, they sell grain to purchase small ruminants, which are kept for sale during lean years (...) labor force is a major constraint mainly during weeding. » (Lang and Cantrell 1984)

The main limiting socio-economic aspects of West African agriculture are population growth and land degradation, changes in cropping systems and subsequent outmigration, and weak government/institutional set up resulting from remnants of colonial and postcolonial periods (Ruthenberg 1980, Ker 1995, Gyasi and Uitto 1997, Yilma 2006). At the same time, agricultural practices are severely restricted by input availability, and although manpower and manure are locally generated, fertilizers, insecticides and herbicides are limited by affordability and market constraints (Yilma 2006, Awo 2010).

3.1 Population

3.1.1 Demographics and outmigration

In the region, the population is mainly rural. For instance, 86% of the workforce of Burkina Faso is primarily employed in agriculture (Sanfo 2010). Birth rates oscillate between 3 and 5% (Table 2). In an agriculture-based society, such a population growth has provoked the depletion of the resources stock, shortening of the fallow periods in shifting agriculture, plus a subsequent massive outmigration of the youth (Kanchebe 2010). Moreover, for 2010, in some districts of the UER, Ghana, a lack of available land was reported.

Table 2: Population increase in Ghana in number and percentage

Year	**Ghana**		**Upper East Region**		**Kassena-Nankana district**	
	Pop. (#)	**Increase (%)**	**Pop (#)**	**Increase (%)**	**Pop (#)**	**Increase (%)**
1960	6728815		468638		93397	
1970	8559313	27,2	542858	15,8	99006	6,0
1984	12296081	43,7	772774	42,3	149680	51,0
2000	18912079	53,8	920089	19,1	149491	-0,1

Source: Kanchebe 2010

In the case of Northern Ghana, which could be extrapolated to neighboring coastal countries, outmigration is seasonal (dry season), and follows a spatial north-south pattern. It is based on work, marital and educational reasons. In the first case, a work force is need in commercial plantations, such as cocoa (*Theobroma cacao*), mining and urban centers (Yilma 2006 Eguavoen 2008, Schraven 2010). Similarly, in Benin, immigrants are attracted to the central cotton-production region for improving their income opportunities (IMPETUS 2008)

Remittances constitute an important contribution to the local economies. In the case of Biu, northern Ghana, about 25% of the families said they were recipients of remittances mostly from the south, and even from abroad (Laube 2007).

3.1.2 Kinship and religion

Eguavoen (2008) drew a profile of the society of the Atankwidi catchment (UER Ghana). Societies are patrilinear, meaning that the belonging of an individual is determined by its affiliation to his/her father's descent group. This determines the way people marry, settle, inherit, and participate in community activities and rituals. Monogamous as well as polygamous marriages are common but less in number than monogamous marriages independent of religion. Divorce and re-marriage is very common, and marriage ages are generally low.

Patrilinear kinship groups live together in so-called *yire* (compound house). Each household has a household head who is usually the husband of the core family, and the oldest household head acts as *yindaana* (compound head) and represents the compound in community meetings. The *yindaana*, also by his spiritual ascendency, is in charge of assigning the rights of land use and managerial decisions. For example, *yindaana* decisions are gender biased, and women require of male consent to hold land and cultivate it. Every *yire* owns three types of land:.(1) the land that surrounds the compound (*semane*) more fertile, collectively cultivated and destined to the production of grains, (2) bush farms (*vaam*) less fertile, located a few km away from the compound house, and frequently nested in inland valleys dedicated to cultivate other staple and cash crops, and (3) permanent grazing lands (Yilma 2006, Eguavoen 2008).

Settlement patterns are virilocal, i.e., the young women move to the husband's compound after marriage, and all children born into marriages are counted in the father's compound. In case women divorce or get widowed, they may stay or return to their fathers´ compound (Eguavoen 2008)

The majority of rural people are so-called traditionalists. The number of Christians (Catholic, Protestant and Pentecostal) and Muslims vary according to the area. Syncretism is widespread. Religious affiliation may differ among members of a compound or household. Young people tend to be more represented in book religions. Beliefs and fear of witchcraft and evil spirits are very common, and guide people's behaviour in particular situations (Eguavoen 2008). Farming activities rely strongly on traditional beliefs and reciprocity, e.g., the beginning of planting is accompanied by a religious performance by which the *yindaana* sacrifices a small animal for a good harvest to the ancestors on behalf of the *yire* (Laube 2007).

3.1.3 Land tenure and ownership

In north-east Ghana, as well as in several West African regions, land tenure and ownership is based on a traditional common property system, which gives the land administration to chiefs who act as custodians. Thus, land tenure patterns determine settlement patterns (IMPETUS 2008, Schindler 2009, Sanfo 2010). Originally, the first settlers claim the ownership of the land and delimitate by human-made or natural borders. The *yindaana* then, as a custodian, allocates land to members of his family as well as to strangers when needed. The right to inherit land is patrilineal, however, most of the responsibility relies on the communal land holding (Kpongor 2007). Each family has the right to cultivate this land 'in perpetuo', which thus cannot be sold nor leased; some parts can be lent in exchange for small gifts or cash (Schindler 2009).

In Burkina Faso, several studies reveal homogeneous patterns of land tenure and ownership, based on principles of sacredness and collectivity (Boutillier 1964, Drabo and Vierich 1983, Baerends 1988). There is a land chief who performs religious rituals and is in charge of assigning land, although his authority is more moral than pragmatic (Boutillier 1964). In practice, there is an interplay between the land assignation by the local authority and the inheritance of land, acquired via the first occupation conquest or a donation from another group. Sometimes, land re-asignation occurs when the land it is left long enough to allow fallow growth. However, increased land fragmentation has challenged the stability of this system, and translated into inequalities of access to land, since demand exceeded the available land (Gastellu 1978).

Nonetheless, the principle of 'first comer' as the customary land-tenure system is gradually changing due to recent legal reforms, leading to conflicts and land insecurity. In Benin, where all land belongs to the state, the traditional ownership system is respected but a way to privatize the land that is minimally used by landowners also exists (Deng 2007, IMPETUS 2008).

3.2 Off-farm activities

Very few people are employed in activities besides agricultural activities, e.g., teachers who combine farming and teaching. In general, off-farm activities are to increase household incomes. Women are especially active in this respect, through fruit and firewood gathering, petty trade, artisanship and foodstuff trading; shops are common and the sale of processed local food, e.g., roasted groundnut, *pito* (local beer made out of millet or sorghum), or of shea butter fruits (Yilma 2006, Laube 2007).

In all cases, most income generated from off-farm activities is used for the purchase of agricultural inputs (Yilma 2006).

In the case of labor trade, this concerns poor, young and landless persons. However, through selling their workforce 'farm boys' can eventually save enough to buy their own plots, mostly in irrigated areas (Laube 2007).

The plantation of trees and shrubs does not occur frequently. For example, in northern Benin, young farmers focus on cash and food crops like cotton due to their market advantage. In contrast, older farmers plant oil palms, teak and cashew trees, because they believe that these will provide them with income in their old age (Igue et al. 2000).

3.3 Institutions, markets, credit and infrastructure

West African institutions are characterized by fragile structures, weak interconnectivity, poor implementation capabilities, and the persistent lack of human, material and financial resources, which means great administrative deficiencies and limited ability to find appropriate and sustainable solutions; assertions that can be easily extrapolated to markets. At larger scales, market frameworks are weak and almost non-existent for smallholder farmers. In general, governments do not promote agriculture intensification, e.g., use of external inputs and equipment, price controls, access to markets, incentives, etc. (Jagtap 1995). Nonetheless, some exceptions exist, as in the case of cotton and maize, and to a lesser extent rice in Benin and Burkina Faso.

At the regional scale, product trade is poor and occurs at the local level, where agricultural products are sold and exchanged for non-agricultural ones such as sugar, salt or kerosene. Local markets are especially active after the harvesting season due to the farmers' poor storing capabilities (Yilma 2006). The trade of agriculture products (cereals, vegetable crops and livestock) is organized by peasant producers, intermediaries, collectors and semi-wholesalers. The liberalization of the marketing of agricultural products in the 1990s weakened producers' trading power and encouraged intermediates, who take most of the margins, which is aggravated by the absence of farmers' organizations (Sanfo 2010).

Regional studies in Benin, Ghana and Burkina Faso have identified as major market distorting factors of the local agricultural sector: international price fluctuations and protectionist national policies at the international level; non protective international trade policies and local manipulative trading strategies (market lobbies) at national level; and bias in the individual and social customs and practices determined by the recurrent immigration and the media at the individual level (The World Bank 2003, Ouédraogo 2004, Awo 2010).

In the 1980s and early 1990s, the cultivation of maize expanded rapidly at the expense of traditional staple crops, such as sorghum and root crops. The diffusion of early maturing maize varieties, together with fertilizer subsidies, credit and marketing support, was aimed to assure food self-sufficiency and generation of income. Recently, these policies were discontinued due to the low cost/benefit ratio (Hall et al. 2001, Schindler 2009). On the other hand, similar programs like the cultivation of cotton in Benin, Burkina Faso and Togo, have been financially successful, and these now provide about 40% of the national GDP (The World Bank 2004) Ouédraogo 2004). But this increase has also often resulted in undesired effects, such as shortages of arable land, declining soil fertility, and increasing dependence on external inputs (Ouattara 2007).

Although agricultural financing facilities exist, e.g., agricultural Bank of Northern Ghana, participation of smallholder farmers in the systems is very limited due to the farmers' risk aversion, relatively high administrative costs and lack of suitable securities. Banks have defined the sensitive areas of investment as: irrigation to face climate uncertainties, anti-bushfire campaigns, timely acquisition of agricultural inputs, and marketing, storage and processing of agricultural products. It remains a main challenge to fine-tune the amount of capital invested with the terms and conditions of credits, and overall, how to aggregate production and economic efficiency (Sam 1992).

Similarly, the region lacks logistical and infrastructural facilities, like roads, waterways, dams, etc., to promote small agriculture (Jagtap 1995). The existing infrastructure is out of date and often in poor condition due to limited or nonexisting maintenance (Schindler 2009).

Using a common framework, Schindler (2009) introduced household decisions, ecological processes, policies and other external parameters of change of a village in UER (Ghana) in an agent-based model. Considered policies included credit access and dam construction, while population growth and climate change were considered as external parameters. Simulation results indicated that average gross income was more enhanced by credit than by dam construction, but improved credit access led to a much higher inequity in income as compared to dam construction. Furthermore, it was shown that the decline of rainfall triggers a shift towards cash cropping and off-farm activities.

4 Farming and Cropping Systems

4.1 Farming systems

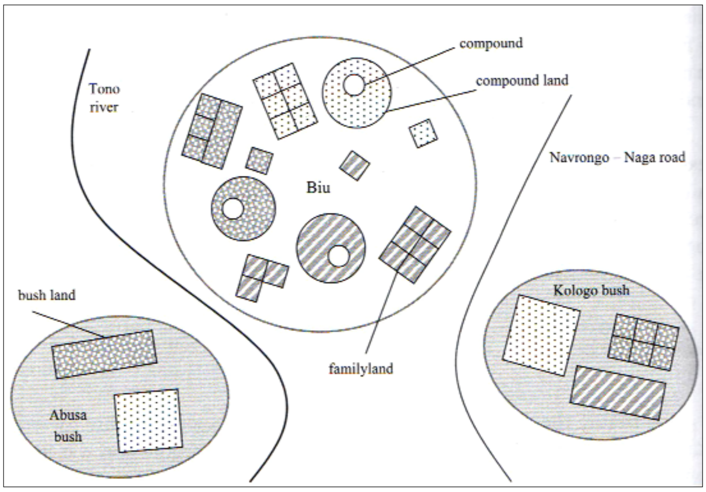
In the past, West African farming systems were based mainly on fallow migratory systems (shifting cultivation), but due to demographic pressure, shrub and woody species have disappeared, the fallow periods reduced to maintain the absolute amount of food produced, and the grazing and marginal lands taken under production. Thus, there has been a transition from fallow-based to a mixture of fallow-based, permanent and other cropping systems (Savadogo 2000, Ouédraogo 2004, Kanchebe 2010).

Moreover, some authors speak of a shift of the ecological zones: desertification of the Sahel, sahelization of the savanna and even savannization of the forests (Aihou 2003) with the corresponding changes in the existing cropping systems.

However, shifting cultivation (in its different forms) still seems to be the fundamental production form, despite the shortening of the fallow periods that lead to a decline in soil fertility (Nye and Greenland 1960, Sanchez 1976), and the expansion of the agricultural frontiers that determine the pressure on forests and conservation areas (Ker 1995).

Spatially, West African small farming follows a 'concentric ring' pattern, where three types of agricultural land are defined: compound land, family land and bushland. The closer the homestead, the more intense is the farming, (Laube 2007) (Figure 7). In the compound land, permanent cultivation of early maturing crop species takes place, with the continuous application of manure, domestic refuse and compost. In the family land, shifting cultivation is practiced, intercropping predominates and the application of manure is poor. The bushland is mainly used for grazing and is devoted to livestock rearing (Bationo et al. 1996, Ouédraogo 2004).

Figure 7: Land types and tenure regimes in Biu, UER, Ghana (Laube 2007)

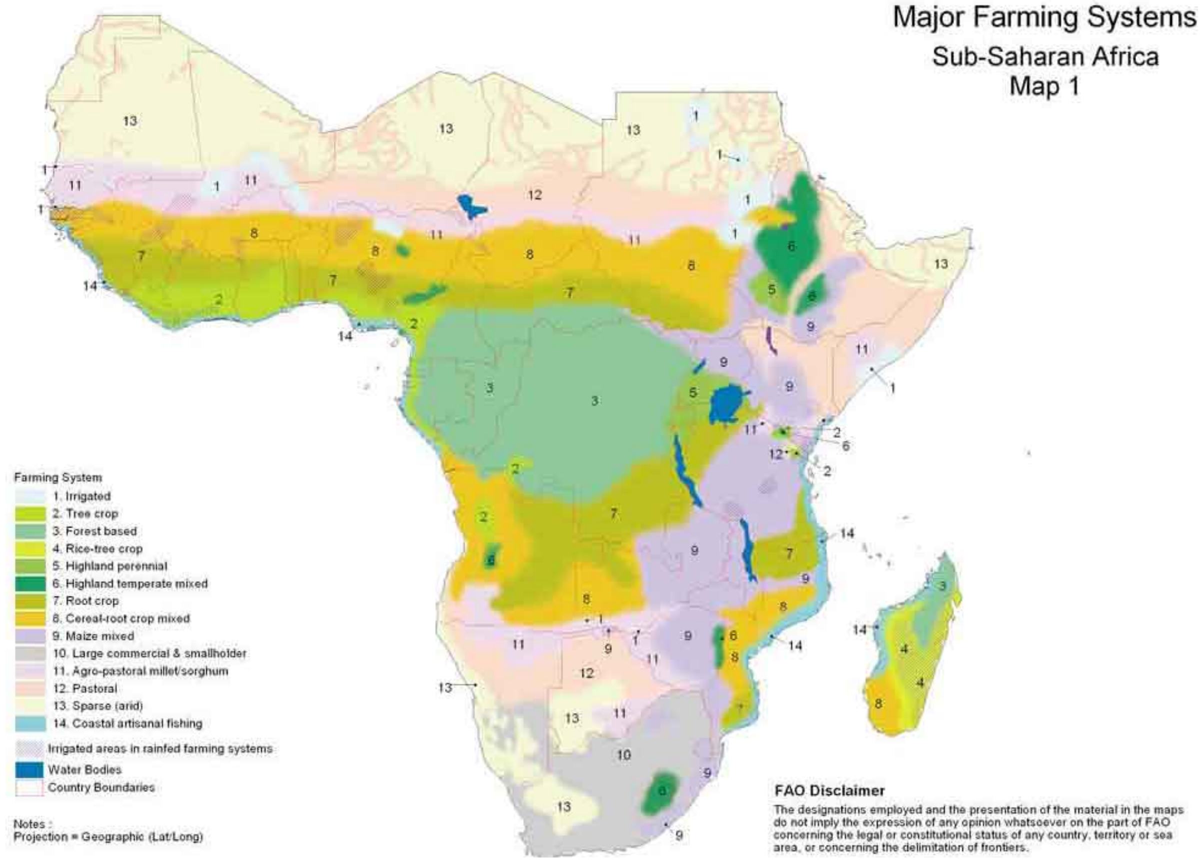


The United Nations Food and Agriculture Organization (FAO) has identified 15 farming systems in Africa based on drivers such as available land area, agricultural population, regional area totals, predominant livelihoods and the prevalence of poverty (Figure 8). Accordingly, the targeted research area (Sudanian savanna) falls mostly in the zone labeled as *cereal-root crop mixed* characterized as follows:

> « (…) extends from Guinea through northern Ivory Coast to Ghana, Togo, Benin, the mid belt states of Nigeria, and northern Cameroon. It accounts for 312 million ha (13% of the area of Africa). A length of growing period of 120 to 180 growing days predominates in accordance with mono-modal rainfall regimes. There is a relatively low population

density, but abundant cultivated land. Communication facilities are poor. The lower altitudes are with higher temperatures and the presence of the tsetse fly that limits livestock numbers and prevents the use of animal traction in much of the area. Although cereals such as maize, sorghum and millet are important in the system, in the absence of animal traction, root crops such as yams and cassava are more important than cereals. A wider range of crops is grown and marketed, and intercropping is far more significant. The main source of vulnerability is drought. Poverty is limited. The number of poor people is modest but at the same time poverty reduction potential is moderate. Agricultural prospects are excellent and the area has the potential to become the breadbasket of Africa and important source of export earnings. » (Hall et al. 2001, p. 37)

Figure 8: Major farming systems in Sub-Saharan Africa (Hall et al. 2001)



4.1.1 Regional variations

In Burkina Faso, the cropping systems vary greatly from one region to another. Staple food crops are sorghum, millet, maize, rice and fonio, and the major cash crops are cotton mainly, followed by groundnut, cowpea and yam, and sugar cane in the southwest (Ouattara 2007). A cereal-root cropping system land-use predominates although cotton-cereal-legume systems also exist (FAO 2010).

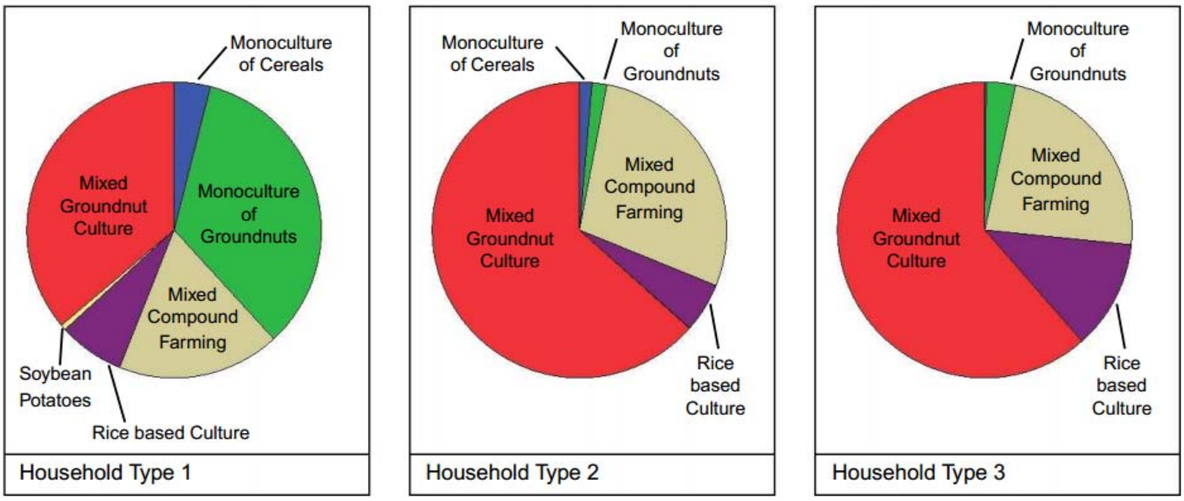
Burkinabe agriculture is mostly rainfed, predominately practiced by smallholder, subsistence farmers, with poor technology and low investments. Staple food occupies more than 80% of area cultivated, and production depends more on extensification (increase in area) than on intensification (increase in yield) (Ouattara 2007). The main limitations for crop production are poor management of soil and water and lack of external inputs such as nutrients, labor and pesticides (FAO 2010).

In the farming systems of northern Ghana, compound farms are fragmented and used for the production of cereals (millet and sorghum) in combination with beans. Some are heavily manured because they perform also as yards for livestock. In contrast, bush farms are located a few kilometers away from the homesteads and due to their poor fertility rotated with bush fallows. These lands are used to produce groundnut, soybean, Bambara bean, rice, late millet, sorghum and maize, mostly in combination (Yilma 2006, Kpongor 2007).

During the dry season, farming activities are reduced to riparian areas along the riverside and inland valleys where irrigation with pumps or hand-dug wells (where the groundwater table is high) is practiced. Main crops are tomatoes, red pepper and onions, mainly as monocrops (Bangayoko 2006, Sandwidi 2007, Schindler 2009).

Schindler (2009) characterized the predominant farming systems in the Atankwidi catchment in the UER (Ghana) during the rainy season of 2008. Applying a k-mean cluster analysis to a balanced set of indicators three household types were extracted: Type 1, the largest group, roughly corresponds to the middle class with relatively large areas of available land, including a high diversity of land use types and the highest migration rate. Type 2 roughly corresponds to the poor class. It is the second largest group and involves the lowest average land holdings and the lowest labor availability, as well as the lowest income per capita and livestock ownership. The subsistent character of this group is also emphasized by the crops cultivated, consisting of groundnut-based mixed crops for self subsistence and a low proportion of rice for selling. Type 3 represents the small better-off group, with the highest income and livestock assets, but medium land area ownership; this group is less dependent on rainfed farming than the Type 1 due to its focus on irrigated cash crops and benefits from non-farm activities (Figure 9).

Figure 9: Predominant cropping systems in the Atankwidi basin depending on household type (Schindler 2009)



The farming systems of Borgou (northern Benin) are based either on cotton or livestock, and as mentioned above, cotton production has governmental support. Farming areas have increased through the extensive use of animal traction, as well as the demand for grazing lands, which leads to conflicts in land-use. For instance, in Banikoara, the livestock density has surpassed the carrying capacity of the land in the dry season (Deng 2007).

Such pressure on the land has meant that in central Benin shifting cultivation has almost disappeared, and the number of larger sedentary farms (6-12 ha) that concentrate on yam, maize and cotton have increased, often at the expense of the forest remnants (Igue et al. 2000).

In the western part of Benin, the major limitation is availability of land. Half of the farms are smaller than 1.25 ha, while 50% of the farms cultivate cotton and also have large livestock herds (Igue et al., 2000)

Admitting that small-scale farming predominates in the Kassena-Nankana region in the UER, Ghana, 70% of the farms vary from 0.5 to 2 ha and 20% of the farms from 2 to 4 ha; the average size of a compound farm there is 1.3 ha for a family of 8 persons, i.e., 0.16 ha per person, meaning a strong pressure on land, land fragmentation and subsequent depletion of soil fertility (Yilma 2006, Eguavoen 2008).

Including the bushlands, in the Biu district (UER, Ghana) the average farm size in 2001 was 2.4 ha, which increased to 3.0 ha by integrating newly irrigated areas (Laube 2007). In 2007, Laube (2007) found a correlation between available or used land and wealth of the household (Table 3).

In Burkina Faso, farm areas vary between 1.5 and 12 ha, considering both farmland and bushland. In general, they are rainfed and cultivated manually; only rice, sugar cane, vegetable and fruit crops are irrigated and mechanized (Ouattara 2007)

Table 3: Average farm area and household wealth in Biu, UER, Ghana

Household wealth	Mean area (ha)	SD	n
Poor	1,42	0,94	10
Middle	2,28	0,71	8
Rich	4,86	2,77	8
Average	3,0	1,24	26

Source: Laube 2007

4.2 Cropping systems

In general terms, the current West African cropping systems include temporary intercropped land in rotation with fallows, permanently intercropped and mixed farming, and monocrops mostly on a small scale with the progressive inclusion of exotic species determined by socio-economic and environmental settings (Gyasi and Uitto 1997). These cropping systems are mostly characterized by low yields and declining productivity, high risk due to climatic and market uncertainties, labor constraints (mainly for soil preparation and weeding), low use of external inputs (fertilizer, improved hybrids, animal and mechanical power), weak extension services, poor transport and communication infrastructure, and therefore strong orientation towards subsistence (Yilma 2006, Kpongor 2007, Ntare et al. 2007, Schindler 2009).

Diehl (1992), who described the cropping systems in northern Ghana by their geographical location, distinguished cropping systems according to the major components/crop species (Table 4).

Table 4: Dominant cropping systems in northern Ghana

Geographical location	Main components	Comments
Northeast	Millet-based system combined with sorghum and cowpea	Highly populated, growing pressure on soils
Central	Based on maize, sorghum, groundnut and cowpea combined with root crop species like yam and cassava	Population density varies from medium to high
West	Sorghum-based with growing importance of maize and cowpea and yam	Low population density
Southeast	Main crop species is yam complemented by maize, sorghum and groundnut	Population density low to medium

Source: Diehl 1992

In the Atankwidi catchment (UER of Ghana), predominant spatial and temporal arrangements within the cropping systems are (a) permanent mixed cropping (48%), practiced around the compound house, consists of early millet, late millet, sorghum, cowpea and other leafy vegetables, such as tobacco and okra, (b) monoculture of groundnut (29.1%), cultivated together with Bambara bean, cowpea and sometimes late millet, (c) intercrops based on groundnut (7.8%) in lands not suitable for other more demanding crop species (sandy-loamy and gravelly soils), thus there is a trend to cultivate them in bushlands; interestingly, these are cultivated by women to supplement the family diet with protein and to earn money, (d) monocultures of cereals (13.7%) in distant bushlands; sorghum, rice, late millet and maize are cultivated alone or in combination, e) rice-based cultures, occasionally in combination with cereals or groundnut (0.7%), and f) monocultures of soybean, combined with sweet potatoes, red pepper, and other vegetables (0.7%). However, productivity is very low, and average yields rarely exceed 1 t/ha, with the exception of rice, where cultivation is restricted to small plots in swampy areas (Schindler 2009).

In Zoundweogo (southern Burkina Faso), farmers concentrate on the production of staple food. Together with the 'concentric ring' pattern, the farmers' selection criteria of crop species are driven by soil types based on nutrient availability and water retention, which are determined mainly by slope and soil texture. In the rainy season, maize is cultivated for a short growing season in the compound fields in soils enriched by manure. Mixed cropping with cereals occurs in less fertile soils with water availability limitations (family/village or bush fields). There, millet, sorghum and also rice are intercropped with groundnut as a strategy to cope with rainfall variability (Leenaars 1998).

4.2.1 Main crop species

Maize (*Zea mays)* was introduced in the West African region by the Portuguese in the 16th century, and since then gained importance and found its way into the traditional agricultural systems. In the Sudanian savanna, maize is usually grown in intercropping with legumes (groundnut and cowpea) and also in combination with other cereals like sorghum and millet. Nonetheless, in the research area, its cultivation area is increasing at the expense of sorghum, millet and rice, following a southwards trend (Sallah 1992).

Maize cultivation is demanding with respect to N, SOM and P, and for this reason it is cultivated on virgin lands, leading to the rapid depletion of the fragile Sudanian savanna soils, and shortening of the fallow period, etc. (Aihou 2003).

Sorghum (S*orghum bicolor, Sorghum vulgare*), commonly called 'guinea corn' or 'red millet', is widely cultivated in the research area. It originated in eastern Africa where its major variability can be found. Accordingly, sorghum has developed various morphological and physiological adaptations that contribute to its optimal fit, as for instance its resistance to drought. Thus, it performs well with rainfall between 400 and 600 mm/year, which is too dry for maize. The response of sorghum to management is diverse and depends on the variety. Local varieties are poorly responsive, but improved ones respond well to fertilization. Normally it is cultivated in combination with other crops (Schipprack and Abdulai 1992).

(Pearl) millet (*Pennisetum glaucum*, *Pennisetum typhoides*, or *Pennisetum americanum*) is the main staple food in the region. Its paramount importance is evidenced by the fact that Niger and Burkina Faso are among the top ten world producers (Lang and Cantrell 1984). Farmers combine the cultivation of two varieties of millet in the short and long season to profit as much as possible from the length of the rainy season. Early millet (*Pennisetum typhoides*) is cultivated in the compound lands, profiting from the higher fertility of soils and care, intercropped with other cereals like late millet (*Pennisetum spicatum*) or sorghum and, in family lands, together with cowpea and groundnut (Eguavoen 2008).

The cultivation of sorghum, maize and millet is important for the provision of carbohydrates to the local diet, and also by the generated byproducts such as the straw for fuel and foliage to feed animals. Their cultivation is strongly influenced by local traditions. In northern Ghana, it is considered an exclusive male activity (women focus on groundnut, rice and vegetables), patrilineally transmitted and subject of rituals (Eguavoen 2008).

Groundnut (*Arachis hypogea*) is the main legume cultivated in the Sudanian savanna together with other leguminous species (see below). The major contribution of these crops is fulfilling the protein demand of the local people (Marfo 1992) and the provision of fodder of high quality for livestock (Slingerland 2000).

Groundnut is preferred due to its ability to produce well under soil-moisture-deficient conditions (Marfo 1992). It is also a source of external income since it is well sold in the market and even exported (Ntare et al. 2007). However, its productivity is only about 50% of the potential, and despite the existing technological alternatives, yields decline (Williams 2002). Aflatoxin is considered the major constraint in groundnut cultivation through its harmful potential effects on human health.

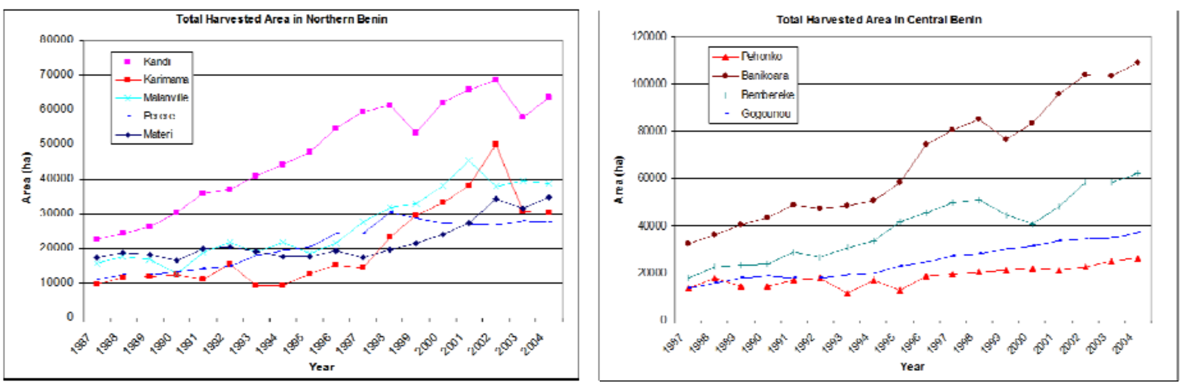
Bambara bean (*Vigna subterranea*) and cowpea (*Vigna unguiculata* L.) are legumes indigenous to West Africa and pigeon pea (*Cajanus cajan*) to Asia. The latter is mainly cultivated either near compound houses, to delineate farms, as well as intercropped in family lands (Marfo 1992).

Through its importance as a cash crop (together with maize), cotton (*Gossypium hirsutum*), has received wide attention from the African governments, especially in the francophone countries (Slingerland 2000). The *Centre de Cooperation International en Recherche Agronomique pour le Developpement* (CIRAD) reported good adoption of improved varieties, mineral fertilization, phytosanitary measures and animal traction in the framework of (a) close research-extension-farmer relationship, (b) provision of input credits, and (c) guarantee of market outlets, which are a determining factor in the boost of cotton cultivation in francophone countries (The World Bank 2004, Gray 2005). But there are reports in western Burkina Faso that this intensification, although more profitable than traditional practices, has led to the decline of soil physical and biological fertility, and environmental degradation (Ouattara 2007, McCauley, 2003). Since 2003, the Burkina Faso authorities have been giving serious consideration to planting genetically modified cotton to counteract the attack of caterpillars (e.g., *Heliothis* sp.) that have developed resistance to pesticides (Ouedraogo 2003).

4.2.2 Cultivated area

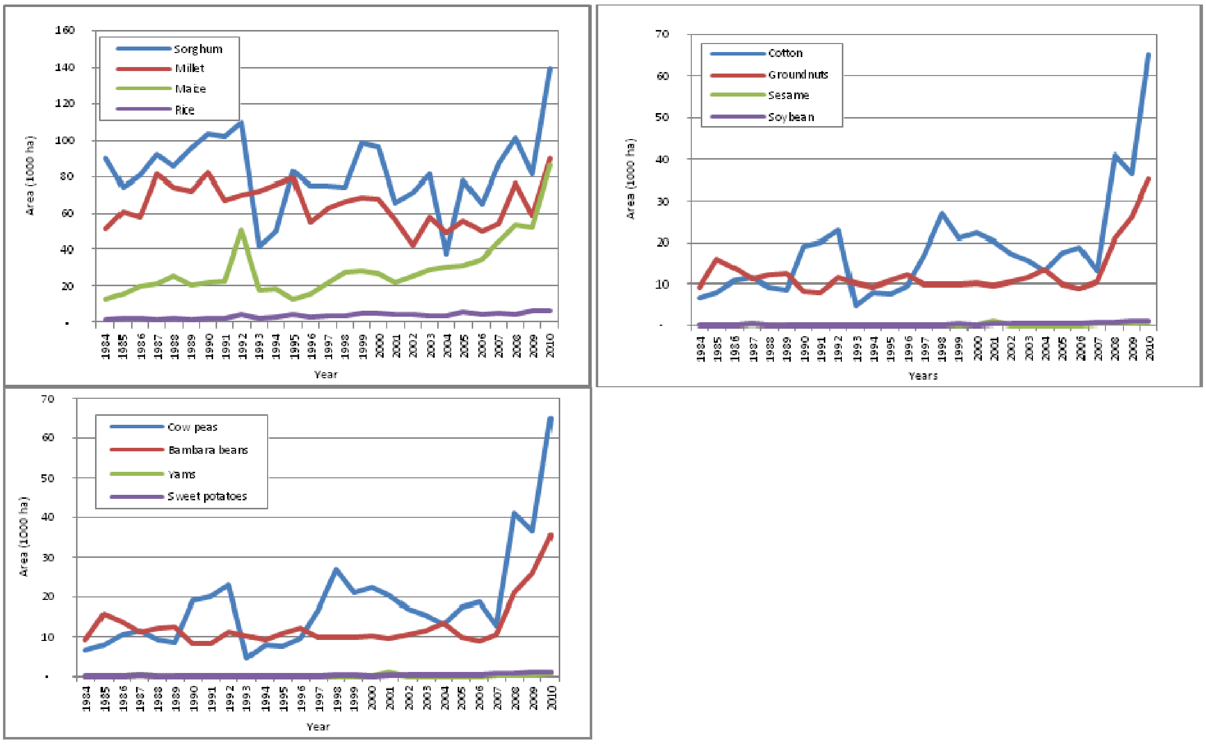
The evolution of total cultivated area in the cereal-root zone depends on the settling history and other socio-cultural and economic factors (Hall et al. 2001), but in general it has grown through land-conversion processes and seems to have reached its limits (Figure 10). For instance, in northern Benin, cotton cultivation increased continuously until the first years of the 21st century when an abrupt slowdown occurred, apparently due to the availability of land and the privatization of the marketing system.

Figure 10: Evolution of harvested area (1987-2004) in selected districts of northern and central Benin (CARDER/MDR 2000, INRAB 2006)



In Burkina Faso, at the southern border of the cereal-cotton zone, where forest and savanna reserves host virgin and fertile land, the boom in harvested area is continuing. However, harvested areas fluctuate mainly due to water availability. The variation in the harvested areas concerns mostly the rainfed crops (sorghum, millet, maize, cotton, groundnut and cowpea), which depend on the monsoon and have considerably higher risks; a stagnation situation is observed for sweet potatoes and yam. The rice area fluctuated less, since rice is an irrigated crop (Figure 11) (Sanfo 2010).

Figure 11: Evolution of harvested area (1984-2010) of selected crops in south-western Burkina Faso (Agristat (1984-2007), DGPER/MAHRH (2006, 2010))



4.2.3 *Average yields*

Yield as the most important proxy of land productivity reveals the limitations and uncertainties that farmers face. Low yields are characteristic in the region (Table 5) (Diehl 1992).

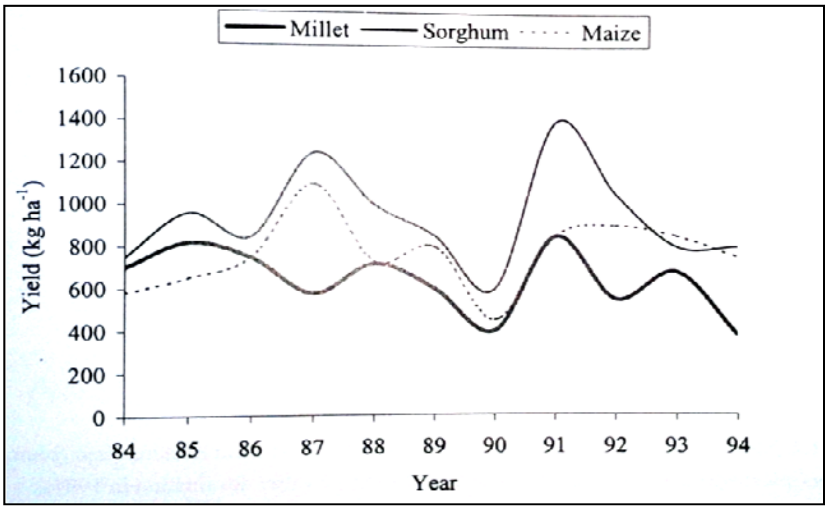
Table 5: Mean yields of major crops in five villages of northern Ghana, 1984 (t/ha)

Crop species	Nakpanduri	Namburugu	Wantugu	Nakpala	Nakpa
Maize	1.18	1.06	0.59	1.19	0.53
Sorghum	0.86	0.75	0.36	1.16	0.39
Millet	1.09	0.69	0.30	1.03	0.28
Cowpea	0.29	0.32	0.12	0.12	0.24
Groundnut	0.54	0.71	0.29	0.60	0.45

Source: Diehl 1992

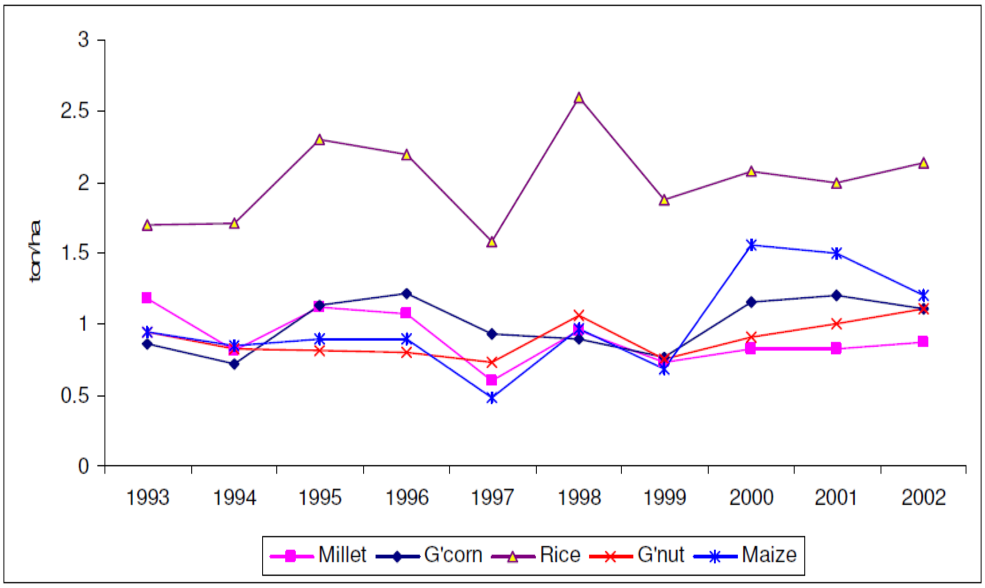
These variations are attributed principally to ecological and managerial limitations. Thus, combinations of soil qualities, cropping techniques, crop varieties, etc., will lead to a wide range of yields, which will vary from year to year depending on the highly variable rainfall (See Figures 2 and 3) (Singerland 2000). The Ministry of Agriculture and Animal Resources (MAHRH) in Burkina Faso tracked the average yields of three main cereals in Burkina Faso between 1984 and 1994, obtaining an uneven pattern (Figure 12).

Figure 12: Temporal variation of average maize, sorghum amd millet yields in Burkina Faso (MAHRH cited by Savadogo 2000)



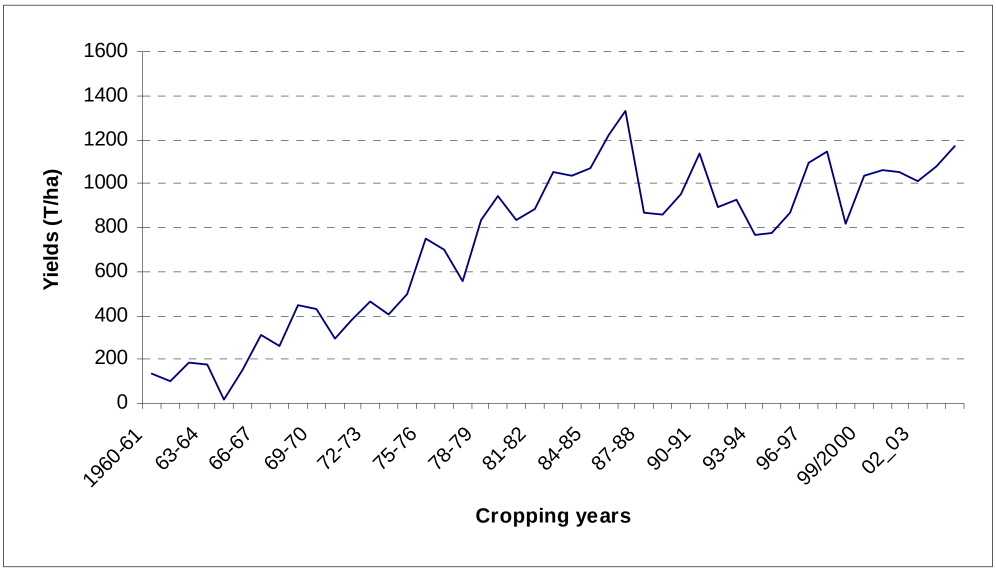
Similarly, Yilma (2006) did the same for the UER (Ghana) between 1993 and 2002 enlarging the sample to rice and groundnut (Figure 13). In both cases, changes are sudden and pronounced, often with variations larger than 50%, which do not seem to follow a seasonal pattern except due to rainfall.

Figure 13: Average yields of main crops in the Upper East Ghanaian Sudanian savanna (Yilma 2006)



In Burkina Faso, the production of cotton has grown continuously since its installation in the 1950s. (Figure 14). The annual sown areas in the 1990s were 100,000-150,000 ha and by 2003/2004 had risen to 460,000 ha (Ouattara 2007).

Figure 14: Evolution of annual cotton production in Burkina Faso (1980-2003) (Ouattara 2007)



Such large variations do not depend on a single variable but rather depend on the interaction of a number of them. Kanchebe (2010), by comparing the yields of millet, sorghum and groundnut in two moderately wet seasons (1987 and 1989) against two very wet seasons (1999 and 2003), did not find conclusive matches between yields and rainfall (Table 6). Similarly, Singerland (1992) contrasted the harvested volumes of grain and straw of sorghum and cowpea in two conditions of humidity (dry and wet) and considering slope and soil texture (sloppy and sandy) in Kaibo (southern Burkina Faso) (Table 7).

Table 6: Average yields of selected crop species in UER Ghana (t/ha)

Year	Wetness	Millet	Sorghum	Groundnut
1987	Moderately wet	0,56	0,64	0,64
1989	Moderately wet	0,75	0,96	0,91
1999	Very wet	0,75	0,69	0,69
2003	Very wet	0,98	0,53	0,53

Source: Kanchebe 2010

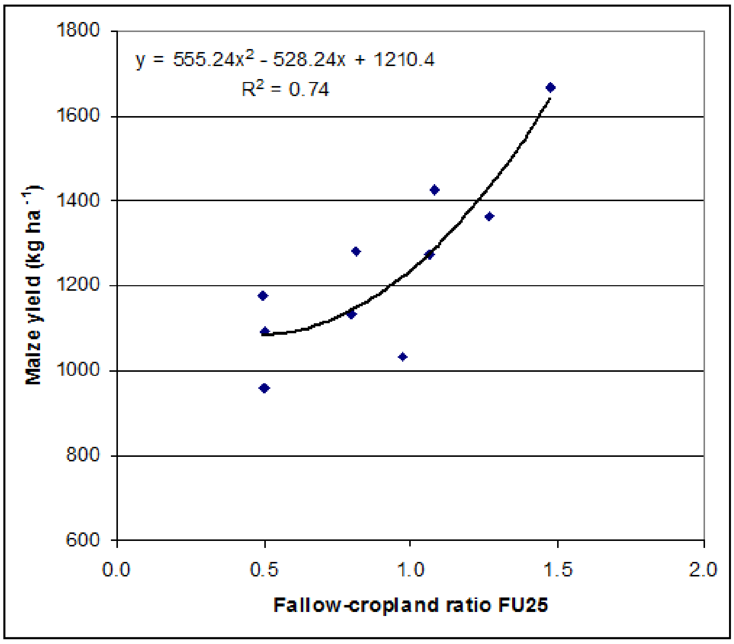
Table 7: Calculated highest and lowest grain and straw yields for sorghum and cowpea under different soil and rainfall conditions in Kaibo, Burkina Faso

Rainfall	Soil	Sorghum		Cowpea	
		Grain (kg/ha)	Straw (kg/ha)	Grain (kg/ha)	Straw (kg/ha)
Dry	**Sloppy**	245	980	157	295
Wet	**Sandy**	3330	7493	2138	4008

Source: Slingerland 2000

Another determinant factor is the age of the fallow, since the poor usage of fertilizers makes soil fertility highly dependent on fallow regeneration. In central Benin, low population density together with large low-impacted savanna areas provide higher average yields of maize compared to northern Ghana (Figure 15).

Figure 15: Regression between observed maize yields in the ten districts of the Upper Ouémé Basin and average fallow-cropland ratio (FU25 = 25% of bush and grass savanna is available as fallow) (Gaiser et al. 2010)



Nonetheless, the regional trend of production increased (FAO, 2003). A 3-year average for 1988–1990 and 1998–2000 shows a slight increase in the productivity of the main West African crops, attributed mainly to land expansion (exploitation of virgin land) and increasing crop productivity (Table 8).

Table 8: Increase in area, production and productivity of main crops of the Sudanian savanna

Crop	Area (%/year)	Productivity (%/year)	Production (%/year)
Cassava	2.6	0.7	3.3
Maize	0.8	0.2	1.0
Yam	7.2	0.4	7.6
Cowpea	7.6	−1.1	6.5
Soybean	−0.1	4.8	4.7
Plantain	1.9	0.0	2.0

Source: FAO 2003

4.2.4 Intercropping

Intercropping, i.e., blending different crop species and also different varieties together, is used as a strategy to minimize risk of loss, as different crops/varieties have different water demands, and different growth stages in the event of adverse rainfall patterns, etc. Nonetheless, it might also reflect cultural perceptions of division of labor between women and men (Laube 2007, Eguavoen 2008, Saidou et al. 2004).

The importance of intercropping is evidenced by Diehl (1992), who surveyed six villages in northern Ghana, identifying that at least 75% of the cultivated land is devoted to multicrops, and 50% to the combination of cereals and legumes (Table 9).

Table 9: Area (%) allocated to main crop combinations in six villages of northern Ghana

Cropping pattern	Binduri	Nakpanduri	Namburugu	Wantugu	Nakpala	Nakpa
Sole	12	16	1	5	0	0
Mixed cereal	27	24	2	0	46	2
Cereal/legume	51	56	80	81	41	58
Root/others	0	0	4	7	11	38
Others	10	4	3	7	2	2

Source: Diehl 1992

In the UER, Ghana, the **combination** of early millet, late millet and sorghum is often found and has demonstrated to be profitable in absolute terms (land equivalent ratio; LER). However, the lack of organic matter is shown to be the main limiting factor (Reddy et al. 1992).

The most widespread combination (cereal and legume) was evaluated by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Kamboinse, central Burkina Faso, considering factors such as land type, slope, plantation density and time of plantation, and found divergent effects on yields for main crops (Table 10) (Tenkouana et al. 1992).

Table 10: Average crop yields in relation to intercropping system, slope and planting density in Burkina Faso in 1982 and 1983

	Sorghum + Cowpea		Millet + cowpea	
	Sorghum grain (kg/ha)	**Cowpea forage dry matter (kg/ha)**	**Millet grain (kg/ha)**	**Cowpea forage dry matter (kg /ha)**
Intercropping	NS	**	*	**
Sole cereal	1512	-	666	-
Cereal + cowpea (5000 plants/ha)	1621	215	600	78
Cereal + cowpea (20000 plants/ha)	1468	525	684	209
Slope + intercropping	**	*	*	NS
Upper slope	489	302	198	118
Mid slope	488	333	238	157
Lower slope	1847	391	901	166
Lowland	3311	457	1262	134
Planting density	NS	**	NS	**
Cereal (20000 plants/ha)	-	-	706	183
Cereal (40000 plants/ha)	1573	483	594	104
Cereal (80000 plants/ha)	1494	259	-	-

NS: not significant at P=0.05, * significant at P=0.01, ** highly significant at P=0.001

Source: Tenkouana et al. 1992

However, a declining trend of intercropping systems in favor of monocrops was observed. In the UER, the percentage of polycultures reduced from 56% in the season 1991/1992 to 45% in 1998/1999; for the same period there was an increase in the proportion of rice in the cropland from 1.5% to 14%, but it predominated in small plots with a maximum size of 0.25 ha (Ghana Statistical Service 2000).

4.3 Management

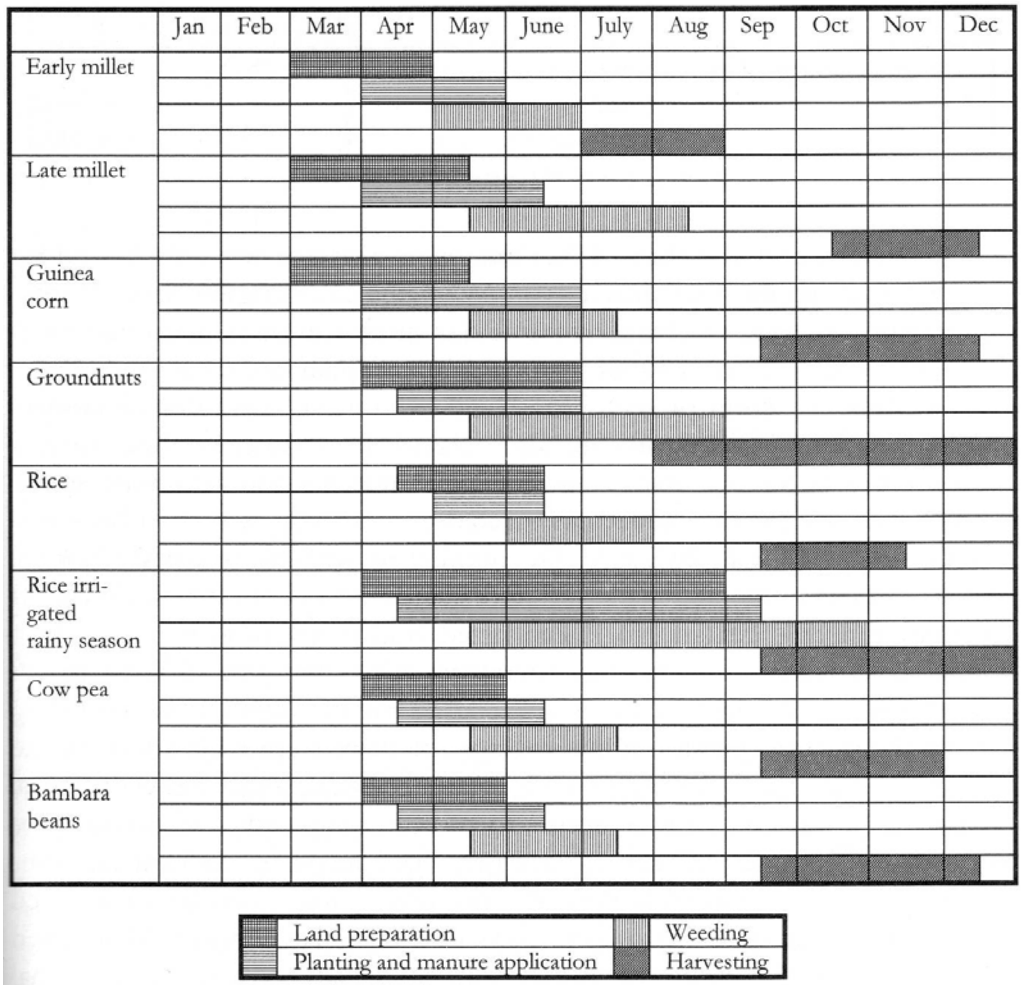
Labor is often stated as the most important input in savanna agricultural land use systems, and contradictorily, management seen among the weaker factors. The failure of the green revolution in Africa, successful in several other places, evidences to a certain extent the weaknesses of the managerial system to boost agricultural productivity due, for example, to lack of infrastructure, poor market development, traditional land tenure and labor customs, and poor institutional and organizational conditions (Aihou 2003). Selected management practices at the field scale are summarized below.

4.3.1 Cropping calendar and planting dates

In Sirigu, northern Ghana, farming starts in May/June with the sowing of early millet, followed by sorghum and late millet, together with other crops such as frafra potato (*Solenostemon rotendifolius*), potato (*Solanum tuberosum*), sweet potato (*Ipomea batata*), and various vegetables, such as cowpea, round bean, onion (*Allium cepa*), tomato (*Solanum lycopersicum*), pumpkin (*Cucurbita* spp) and sorrel (*Rumex acetosa*). Mango trees (*Manguifera indica*) are spread as well as cashew (*Anacardium occidentale*), shea nut (*Vitellaria paradoxa*) and Dawa-dawa (*Parkia biglobosa*) (Eguavoen 2008).

Mixed cropping predominates; early millet and sorghum are planted together with pumkin, beans and okra by mixing their seeds. A few weeks later, groundnut is complementarily sown. Most vegetables are grown in gardens next to the compound house. The farming period lasts from March/April to November/December (Figure 16) and labor distribution is gender specific and sequential, women focusing on vegetables and groundnut and men on cereals (Laube 2007, Eguavoen 2008).

Figure 16: Peasant seasonal farming calendar in Biu, Northern Ghana (Laube 2007)



In Burkina Faso, farming activities follow a similar sequence differing somewhat in the dates. The cropping season generally starts in June with the start of the rains (high variability of rainfall periods). Tillage is manual on sandy soils while on harder soils animal power is used; special attention is paid to the organic matter (manure, compost, crop residues, etc.) to be applied one or two months before ploughing and left in the field. And at the end of the season, crop residues are either removed for use as fuel and fodder or left in the field for decomposition (Ouédraogo 2004).

4.3.2 Fertilization and manuring

One of the major constraints of Sub-Saharan African agriculture is the lack of nutrients or, more precisely, the negative balance of nutrients. This assertion comprises two main aspects. First, the export of nutrients through the harvest, the removal of crop residues and leaching or erosion processes surpasses the input of nutrients through fertilizers. It is common practice for the farmers to increase soil fertility by concentrating nutrients in the homestead by the use of animal manure and bringing crop residues from distant bush farms. Second, the growing pressure on land that reduces the fallow periods (Stoorvogel and Smaling 1990, Tilander 1996, Tossah 2000, Kpongor 2007).

Nutrient depletion has been estimated at 40 kg/ha/y in Liberia, Togo, Benin and Camerun. In Burkina Faso, the mean net loss of nutrients per hectare cropland is 22 kg/ha of N, 7 kg/ha of P and 18 kg/ha of K (Stoorvogel and Smaling 1990). On average, farmers obtain 33% of the yields that the experiments in research stations produce (Tossah 2000). A simulation of the cultivation of sorghum under these conditions shows a constant decrease on home as well as on bush farms. It has been simulated that maintaining crop residues in the bush farms would satisfy 50% of the existing demand for nutrients (Kpongor 2007). For Burkina Faso, it has been calculated that double the amount of crop residues and manure is produced that is needed (Sedogo et al. 1992); however, 90% of the straw is used as fuel and 7-9% as fodder (Tilander 1996).

Therefore, the application and proper use of inorganic fertilizers and organic amendments are seen as key factors to increase yields, stabilize the sustainability of agricultural land use systems, and overall, to assure the food security of the region.

About 25% of the increase in yields worldwide in the last decade of 2000 was due to the use of improved technologies such as the use of fertilizers (Bindraban et al. 2000). In contrast to the situation world-wide, the use of mineral fertilizers in Sub-Saharan Africa remains very low. While in East and South Asia the average application is of 100 and 135 kg/ha, and in Latin America 73 kg/ha, in Sub-Saharan Africa it reaches barely 9 kg/ha (FAO 2004). It is argued that the reasons for this are the high cost of synthetic fertilizers, which are between 2 to 6 times higher than in Europe, North America or Asia (Sanchez 2002) and unaffordable for smallholders. It has also to be mentioned that the response of fertilizers is limited by the varied soil conditions, and low and/or erratic rainfall patterns (Kpongor 2007).

In the Bolgatanga district in the UER, Ghana, only 33% of the farmers apply mineral fertilizers, and generally in low doses. In contrast, in northern Benin 75% of the farmers use mineral fertilizers, but not for all crops. Fertilizers are subsidized for cash crops like cotton, but the applied fertilizers do not always perform well (Igue et al. 2000). However, modest applications of inorganic fertilizers have been tested and shown different outputs, almost doubling the yields of sorghum, but with little effect on pearl millet production (Roth and Sanders 1984). Due to its high cost, fertilizer application only becomes profitable through use together with plowing and irrigation (Matlon 1984, Yilma 2006, Laube 2007).

Several studies have evaluated the impact of fertilizers in the region. In the Nyankpala Agriculture Experiment Station (NAES) in Tamale (Ghana), crop rotation and fertilization were tested. Cereals (maize and sorghum) were very responsive to N and P fertilization (60 and 80 kg/ha). Groundnut used well the remnants from the precedent application but should not be cultivated twice in the same plot. Other leguminous crops, such as cowpea and pigeon pea, performed well in the rotations in terms of yields (Schmidt and Frey 1992). Highest maize yields were obtained in rotation with cowpea, whereas mixed cropping with cowpea produced less maize. Yields in monocropping and relay intercropping are lower compared to crop rotation but higher compared to mixed cropping. Nitrogen and P application increased maize yield, but there were no differences between cropping systems. The Land Equivalent Ratio (LER; area under mono- and inter-cropping needed to produce equal yield) and Area*Time Equivalent Ratio (ATER; which includes the time of occupation of land) indicate both higher productivity in intercropping of maize and cowpea compared to monocropping but show no advantage over crop rotation systems (Härdter 1989).

The use of phosphate rock as a source of P is common in Togo. Since the 1970s, large deposits in the maritime region have been exploited. Generally, use is in a one-time large quantity application instead of small annual applications. Its residual effectiveness has been analyzed by comparing it against soluble fertilizers with maize in the savanna region between 1984 and 1988. Results indicate that after three years the same maximum yield still can be obtained with both sources of P, i.e., soluble fertilizers and phosphate rock (Tossah 2000).

Organic matter content in cultivated West African soils is poor due to the continuous cultivation (extraction of nutrients) and poor biomass return. The situation is aggravated by the weak structure of the topsoil, and land mismanagement, e.g., conventional tillage in clayey soils of low porosity and high bulk density, and the long distances between the cattle rearing areas and the agricultural fields (Tilander 1996).

Experiments in compost preparation and application on sorghum in Burkina Faso considered three treatments: 0.5 and 10 t/ha in two sites and three different soil types. Yields increased by 45% with 0.5 t/ha and 300% with 10 t/ha. No significant differences were obtained in SOM content but the CEC and pH increased. Compost application also mitigated the effects of delayed sowing. Socio-economic interviews evidenced the farmers' awareness of the importance of compost for improvement of yields and soil quality, but land tenure, and lack of equipment, organic materials, and manpower required for making compost are the major constraints for its adoption (Ouédraogo 2004).

4.3.3 Irrigation

In semiarid West Africa, the inadequate water supply is considered the major limiting production factor coupled with the negative nutrient balance, especially concerning N and P (Zougmoré 2003).

The irregular rainfall patterns in the area limit the efficiency of mineral fertilizers, therefore, irrigation infrastructure is perceived as a development strategy. Nonetheless, the public investment on small- and medium-scale irrigation infrastructure is low.

At household level, there is an influence of off-farm activities on the irrigation decisions. Expansion of the irrigated area is promoted by credit availability and other financing alternatives, together with the encouragement of the use of mineral fertilizers (Sam 1992, Yilma 2006).

In northern Ghana, irrigation is limited to small areas and mostly during the dry season. Although small dams exist, these are often not functioning due to mistakes in construction, accumulation of sediments, and technical constraints. Bucket irrigation is more commonly practiced using boreholes and hand-dug wells, and pumps when the parcel is located near a river bank. The preferred crops are mostly tomato often combined with other vegetables such as pepper, onions, etc. Agrochemicals such as urea and DDT are also used (Schindler 2009).

Technically, irrigation and fertilizer application must be managed in an integrated manner in order to reduce water and nutrient losses through runoff and percolation, and to increase water infiltration and availability of nutrients for intensified crop prodution (Zougmoré 2003).

4.3.4 Livestock

Livestock plays a multipurpose role in West African agricultural land use and cropping systems. Manure provision, insurance against unexpected events, wealth saving, food provision, traction, inter-house exchange, rituals and dowry payments are among its major uses. The composition, size and ownership regime of livestock are variable, from a small number of goats, sheep and pigs, and some poultry, to larger herds of donkeys, horses, and even camels northwards; southwards oxen and donkeys can also be found (Roth and Sanders 1984, Slingerland 2000, Yilma 2006, Eguavoen 2008, Kpongor 2007, Laube 2007).

Livestock also plays a role in the social structures of small-scale farms. Ownership is a proxy of social status, and gender criteria drive livestock transactions, e.g., women cannot participate in exchange of livestock (Eguavoen 2008, Challinor et al. 2007).

Despite the low volume of cattle, overgrazing is a regional problem (Kpongor 2007). The lack of grazing areas and inexistent fodder production, worsened by the seasonal arrival of nomad tribes (Fulani) from the northern Sahel in the dry season, who collect local livestock and bring them to the open savanna during the dry season have been addressed as the major drivers (Schraven 2010).

However, the growth of livestock populations also had unexpected effects. For instance, in some parts of Benin expansion occured at the expense of conservation areas and led to deforestation and shortening of the fallow periods (Igue et al. 2000). Only few pests attack the cattle, tse-tse fly being the most critical one (Hall et al. 2001).

In order to mitigate these risks, farmers integrate livestock with cropping systems through the collection, exchange and application of dung and manure, which is relatively successful depending on the volume of rainfall. However, crop-livestock integration is not enough to prevent negative nutrient and organic matter budgets. Food security is not possible without the use of external inputs, and the situation is worsening (Slingerland 2000).

In northern Ghana, cattle are the most prestigious animals. They are kept as savings and seldom slaughtered, if they are, then mostly for ritual reasons, and are rarely eaten. Rather people eat poultry as a source of protein: poultry is also used ritually to make small payments. Watering of livestock is an issue, especially in the dry seasons, and dams and irrigation infrastructure are used to cope with this demand. Shepherding is considered as an alternative education where children acquire several skills, e.g., fishing, gathering, hunting, etc. (Laube 2007).

In northern Benin, cattle herds are moved across the farm and grazing lands of the village playing a key role in grazing and manuring close to the homesteads (Deng 2007). In Burkina Faso, crop-livestock integration has several variants. In Tenkodogo (eastern Burkina Faso), the seasonal lack of labor during the harvesting season (July) coincides with the higher quality of pastures and therefore greater herding efforts are needed. Farmer tribes (e.g.Mossi) have developed symbiotic relationships with transhumant tribes (e.g., Fulani), sharing both farming and herding activities, with different degrees of specialization and outcomes, e.g., the Fulani invest low labor in large fields and obtain low yields but maintain a higher, intensive market interaction in contrast to the Mossi who apply more intensive cultivation techniques for higher yields (Slingerland 2000).

However, the performance of these systems is far from sustainable. Modelling exercises in Zoundweogo province (Burkina Faso) have shown that the nutrient unbalance could be overcome by increasing the cash availability for optimizing the transport of manure and crop residues, and the purchase of external inputs (Slingerland 2000).

5 Summary and Conclusion

The farming systems in the WASCAL research area are basically composed by cereal–based cropping systems combined with roots and legumes, and eventually monocrops as cotton, mixed with various degrees of livestock keeping. The production of food, feed and fiber is based on shifting cultivation or semi-permanent fallow systems. The determinants for the diversity of the farm types are rainfall variability, labor constraints, land-tenure systems and lack of infrastructure to facilitate the access to capital (credits for investment) and markets. Farm sizes are usually below 12 ha for cropping and fallowing, including grazing activities. The farms can be categorized according to farm size, degree of livestock integration and market/subsistence orientation. Reasons for livestock keeping are extremely diverse and include manure supply, wealth saving, insurance, traction power, dowry payment or food, or a combination of them.

According to the farm categories, typical cropping systems have evolved, and can be classified according to the type of crop combinations (monoculture, rotation, intercropping and relay cropping) and according to the major crops (millet, sorghum/maize or cotton/maize based cropping systems). The cropping systems follow a north to south gradient (millet-based systems in the northern part of the Sudanian savanna and the other two as transition towards the southern Guinean savanna. Intercropping is the most wide-spread, typically cereal/legume (e.g., millet/cowpea) or mixed cereals (e.g., sorghum/maize). Cash-crop-dominated cropping systems (cotton, rice) are more frequent in Burkina Faso and Benin due to the agricultural policies and subsidies in these countries.

The management of the cropping systems is determined by lack of labor and capital, rainfall variability and nutrient deficiency (N and P). In order to cope with the uncertainties and risk of rainfall variability, farmers vary planting dates according to onset of the rains and distribute planting over a longer time period. They use short- and long-cycle varieties (e.g., early and late millet), intercropping and irrigation. However, the proportion of irrigated land in the Sudanian savanna depends on the agricultural policies and governmental investments in the respective countries. The proportion of irrigated cropland does not exceed 1% o the total cropland area there.

In areas with sufficient availability of land, farmers try to overcome nutrient deficiency through long fallow periods, through clearing virgin land or by increasing manure application with integration of livestock. On the other hand, manure production, transport and distribution is labor intensive, and labor is in some periods of the year a true bottleneck on many farms. The return of crop residues (and nutrients) is often hampered by the need for energy for cooking, feed and construction material. Application of mineral fertilizer is increasing, depending on the access to credits and fertilizers and on subsidies. In some parts of the Sudanian savanna, the degree of soil degradation through nutrient mining has reached serious levels, which necessitate nutrient inputs through mineral fertilizers. Otherwise the soil degradation leads to intensification of off-farm activities (if available) or out-migration (to other regions or to the larger cities), which is often the last option for the farmers and their families.

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Annex. West African Sudanian savanna cropping systems (WASCAL working region)

Location (district(s), region, country)	Cropping system typology (monocrops, intercrops, mixed crop-livestock)	Management intensity (machinery, fertilization, improved seeds, animal traction, etc.)	Orientation of the production (subsistence, commercial, mixed, etc.)	Main (crop) species	Average farm size (ha); and average yield (t/ha)	Property regime (household, compound, community, etc.)	Source
Binduri, Nakpanduri, Namburugu, Wantugu, Nakpala, Nakpa; Northern region; Ghana	Mixed intercrops with varying components depending on the region: mixed cereal cereal/legume, root/other, etc.	Rainfed-based with low of use of fertilizers, improved varieties, animal and mechanical power	Subsistence agriculture	Maize, millet, sorghum, cowpea, groundnut, yam	3.6 to 5.8 maize (0.53-1.19); sorghum (0.36-1.16); millet (0.28-1.09); cowpea (0.12-0.32); groundnut (0.29-0.60)	Household predominates	Diehl 1992
Bolgatanga, Bio; Kassena Nankana disctrict, Upper East Region, Ghana	Agro-pastoralist with predominant mixed systems (cereal-based) and additional non-farm activities	Rainfed-based with low use of fertilizers, improved seeds, animal and mechanical power. In the dry season boreholes and chemical fertilizers are applied	Subsistence agriculure with small excedents	Millet, sorghum, rice and groundnut in rainy season; tomato and onion in the dry season; and pumpkin, okra, potatoes, sweet potato, etc., on the compound farm	0.5 to 2.4	Household (compound and bush) farming predominates	Yilma 2006, Laube 2007, Eguavoen 2008, Schindler 2009
Center/east/north Burkina faso	Mixed intercrops (cereal-legume), and transhumant pastoralism	Rainfed-based, traditional practies and with low use of external imputs.	Subsistence agriculture; and commercial for pastoralists (Fulani)	Sorghum, millet, maize, sesame, cowpea, cotton and vegetables	15,1 Maize (2.3-4.5), millet (0.23-1.3), sorghum (0.5-3.3), cowpea (0.078-0.5)	Household and transhumant sheperd communities	Savadogo 2000, Bagayoko 2006, Tenkouana et al. 1992
South Burkina Faso	Mixed intercrops (cereal-legume-root) and cash	Rainfed-based	Subsistence agriculture, small excedents for selling	Millet, sorghum, cowpea, groundnut, yam, sweet potato. Cotton (cash)	--	Household predominates	Slingerland 2000, Sanfo 2010)
Alibori, northwest Borgou, west Benin	Agro-pastoralists, livestock (small ruminants, cattle) with mixed and monocrops	Growing use of animal traction and fertilization, encouraged by government support	Mix of agriculture subsistence and commercial plots	Cotton (subsidized); yam, sorghum, millet and cowpea for self consumption	Lack of land (northwest), reduction in the average farm area 1.25	Household predominates	Lawrence et al. 1998, Igue et al. 2000

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