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Review

Farming in the West African Sudan Savanna: Insights in the context of climate change

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Farming is the main livelihood activity in semi-arid rural West Africa, involving the largest portion of the population, contributing significantly to the regional economy and intimately intertwined with current environmental problems. Key vulnerabilities of the Sudan Savanna include its ecological fragility, institutional weakness, high levels of poverty and food insecurity, and political and economic instability, now aggravated by climate change. The characterization of current farming and cropping systems in the Sudan Savanna is the key for understanding and proposing meaningful adaptation strategies at the field, farm, local and national levels. This review begins by examining the agroecological (biophysical) profile, detailing climatic, edaphological and hydrological qualities. Next, the main socioeconomic features: demography, culture, and organizational and economic institutions are summarized, followed by a characterization of the main farming and cropping systems and associated management. The paper concludes by offering an outlook on targeted activities, interventions and strategies for cropping and farming systems to cope and adapt to climate change and variability, as well as soil fertility challenges within the current socio-ecological context.

Key words: Farming systems, cropping systems, climate change, West Africa, resilience.

INTRODUCTION

West Africa is considered to be one of the regions likely to be most affected by climate change. Its vulnerability seems highly correlated with its climatic and geographical peculiarities. From south to north, five main bio-geographical zones are identified: rain forest, forest-savanna ecotone, savanna, Sahel and desert. A development gradient roughly corresponds with the geographical one, with the best agricultural conditions and highest levels of economic and trade activities in the south, decreasing as one move northward.

The savanna occupies about 60% of the surface of tropical Africa, with its appearance and degradation status largely determined by human activities (Laube, 2007). Depending on annual rainfall and growing season length, it is classified as the Guinea (sub-humid) savanna (900-1200 mm rainfall per year and 140-190 growing days), and Sudan (semi-arid) savanna (600 to 900 mm rainfall per year and 90-140 growing days) (Ker, 1995) (Figure 1).

The agricultural potential of the Sudan Savanna has been largely acknowledged, but several factors limit the realization of its potential. Insufficient water availability due to high rainfall variability and frequent droughts (Challinor et al., 2007), together with poor soil fertility (Sanchez, 2002) are considered the main ecological constraints; in addition to poor farmers' limited

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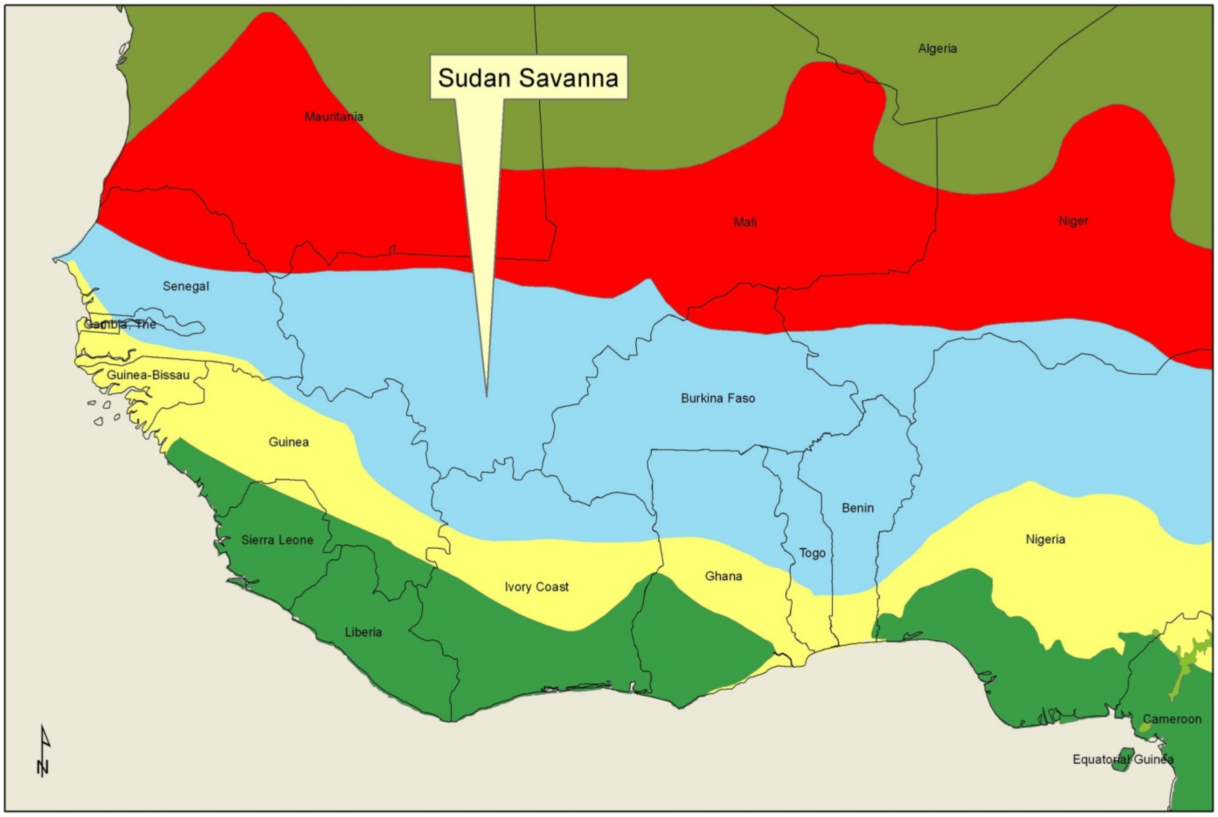

Figure 1. The Sudan Savanna region. Source: Based on White 1983.

technical, managerial and financial capacities (Roth and Sanders, 1984; Dvorak, 1993) and the general structural, economic and institutional weaknesses of Sub-Saharan countries (The World Bank, 2009). Agriculture's importance, as the backbone of the region's economy and providing livelihoods for, and the need for it to adapt to changing climate and global economic conditions necessitates the identification and characterization of cropping and farming systems.

This review paper offers a critical characterization of predominant cropping and farming systems of the West African Sudan Savanna, detailing the agroecological and socio-economic regional profiles and describing some relevant features of systems. A concluding section connects this state-of-the-art with an outlook on pathways of adaptation to climate change.

Geographically, the area covered by the paper is restricted to northern Benin, southwestern Burkina Faso and northern Ghana. By their ecological similarities, but neither political nor socioeconomic, certain degree of extrapolation has been assumed. Therefore when we use the term Sudan Savanna it is in reference to the aforementioned regions.

Methodologically, this review relays on the compilation and synthesis of primary literature on cropping and farming systems. Empirical studies were revisited to argument the compiled assertions and open research questions were underlined and reframed foreseeing potential coping measures and adaptation strategies to climate change.

AGRO-ECOLOGICAL PROFILE

In general, the West African climate is governed by the Inter Tropical Convergence Zone (ITCZ) and strongly influenced by the West African monsoon (GEF-UNEP, 2002). Incoming solar radiation is relatively constant, as are the mean monthly and annual temperatures. Diurnal temperatures can oscillate strongly, from 15°C during the night to more than 40°C during the day (Sandwidi, 2007; SARI, 2011). In addition, recent observations have found a rise in the average temperature of 1°C between 1960 and 1990 (Ouédraogo, 2004; Sandwidi, 2007). The region is generally poor in water resources. The main constraints are distance to the ocean, the monomodal rainfall regime, and groundwater table of crystalline rock with poor aquifer conditions, resulting in highly variable ground water levels.

Rainfall follows a decreasing gradient from the south to the north. In the Upper East Region of Ghana (UER) the monomodal rainfall regime has a duration of 3 to 5 months between April and October, depositing between 900 and 1000 mm; the remaining, up to seven months,

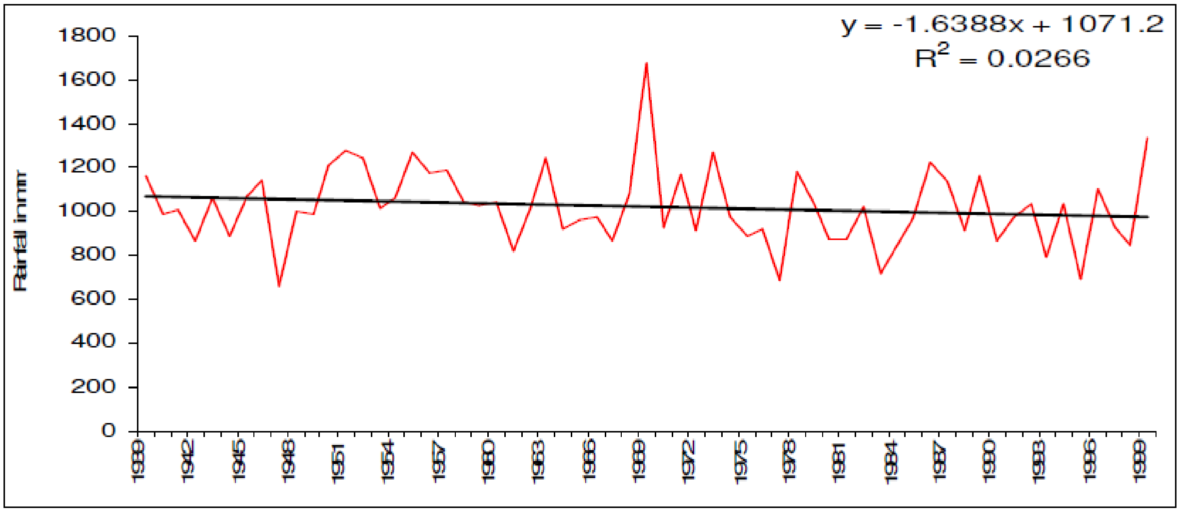

Figure 2. Variation of annual rainfall between 1940 and 1999 Upper East Region, Ghana. Source: Obeng-Asiedu 2004.

are dry (Kpongor, 2007; Sandwidi, 2007), conditions fairly extrapolable to the region. The high rainfall variability is remarkable, the average annual rainfall between 1939 and 1963 in the Volta basin, 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%, making any predictions regarding expected rainfall amounts highly uncertain (Yilma, 2006; Kpongor, 2007) (Figure 2). Rainfall intensity is also highly variable, as rainfall events of 120 to 160 mm/h are not uncommon (Kowal and Kassam, 1978).

The region lies predominantly on a Paleoproterozoic granitoid formation with varied Neoproterozoic and Cenozoic layers in different locations (Sandwidi, 2007). The landscape is gently rolling to flat with slight depressions known as 'inland valleys' where water discharges into larger water bodies (Sandwidi, 2007). The top of the hills are frequently iron-capped with shallow soils. Thus, upper slope soils are usually sandy, well drained and in some cases with rock outcrops, which turn clayey (yellow-brown) on the middle slope. At the foot slopes, 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. Variable contents of coarse fragments (e.g. plintite or quartzitic gravel) with vertical and horizontal variations are a common feature of all soils.

As the soils in the savanna developed in large part on acidic metamorphic rocks they have low activity kaolinitic clay, are coarse textured in the topsoil and, depending on the cultivation history, have low levels of organic matter. As a result, supply of nitrogen (N) and phosphorus (P) and sometimes micronutrients is low. In addition, they are very susceptible to erosion and compaction. A number of soils with high clay content occur either in valley bottoms or in alluvial plains. Frequently, subsoils have a clayey texture with sandy to loamy top soils. This change in texture from the top to the subsoil is conducive to waterlogging (especially after heavy rains) and surface run-off, and in combination with high rainfall intensities in the savanna zones, they are very susceptible to erosion and compaction (Jones, 1987).

As climate changes from sub-humid in the south to semi-arid in the north, water supply to 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).

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, together with nitrogen, are considered the main production-limiting nutrients (Sanchez, 1976; Kowal and Kassam, 1978). Although the total P content can be relatively high, if soils have clayey textured subsoils 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). Thus, it can be concluded that the two major natural drivers currently influencing agricultural production in the region are: (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 currently affected by human-induced degradation (Oldemann et al., 1991; Zougmoré, 2003).

SOCIO-ECONOMIC PROFILE

Several socio-economic aspects limit the performance of West African Sudan Savanna agriculture, such as population growth, insecure land tenure, lack of capital and credit, limited accessibility to markets and dependence on fertilizer imports all of which are fuelled by some extent by the weak government/institutional settings (Ruthenberg, 1980; Ker, 1995; Gyasi and Uitto, 1997; Yilma, 2006). High national birth rates, oscillating between 3 and 5%, are correlated with depleted land and nutrient resources and the shortening of the fallow periods in shifting agriculture (Lambin et al., 2001; Kanchebe, 2010).

Land tenure and ownership is based on traditional common property systems. They are generally determined by settlement patterns and chiefs act as custodians (IMPETUS, 2008; Schindler, 2009; Sanfo, 2010). In northern Ghana, the right to inherit land is patrilineal (Eguavoen, 2007), and neither selling nor leasing are practiced but lending in exchange for small gifts or cash occurs (Schindler, 2009); however most of land holding responsibility is communal (Kpongor, 2007). In Burkina Faso, land is regularly acquired via first occupation, conquest or donation, but sacredness and collectivity determine land tenure and ownership: a land chief assigns land following religious rituals, e.g. when the land is left long enough to allow fallow growth (Boutillier, 1964; Drabo and Vierich, 1983; Baerends, 1988). Nonetheless, the principle of 'first comer' as the customary system is gradually changing due to recent legal reforms, giving place to private property (Deng, 2007; IMPETUS, 2008).

Off-farm activities are crucial for increasing household incomes and supporting agricultural activities. Locally, women are especially active, through fruit and firewood gathering, petty trade, artisanship, trading and the sale of processed local food, local beer, etc. (Yilma, 2006; Laube, 2007). Labor trade is minimal and involves young, poor and landless people. In coastal countries, seasonal out-migration to commercial plantations, mining areas and urban centers is a crucial strategy (Yilma, 2006; Eguavoen, 2007; Schraven, 2010) with remittances resulting key contributors to local economies (Laube, 2007).

West African institutions are structurally fragile, poorly interconnected and lacking in implementation capabilities, as result of persistent scarcity of human, material and financial resources. Agricultural markets, for instance, are almost non-existent for smallholders (Ayuk, personal communication, 2010). At the regional scale, product trade occurs at the local level organized by peasant producers, intermediaries, collectors and semi-wholesalers and products are sold and exchanged for non-agricultural ones such as sugar, salt or kerosene. 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), but exceptions exist, as in the case of cotton and maize, and to a lesser extent rice. Cotton cultivation in Benin, Burkina Faso and Togo, have been financially successful, and provided about 40% of the national GDP around the year 2000 (The World Bank, 2004; Ouédraogo, 2004), although this increase often resulted in undesired effects, such as shortages of arable land, declining soil fertility, and increasing dependence on external inputs (Ouattara, 2007).

In this regard, regional studies have identified several major distorting factors including: international price fluctuations and protectionist national policies at the international level; trade policies and market lobbies at national level; and bias in individual and social customs and practices determined by recurrent immigration and the media at the individual level (The World Bank, 2003; Ouédraogo, 2004; Awo, 2010; Sanfo, 2010). At the same time, the region lacks logistical and infrastructural facilities, such as roads, credit facilities, waterways, dams, etc., to promote smallholder agriculture (Jagtap, 1995). The existing infrastructure is out of date and often in poor condition due to limited or non-existing maintenance (Schindler, 2009).

FARMING AND CROPPING SYSTEMS

Farming systems

Farming systems are characterized as extensive, low external input, mixed crop and livestock systems of a subsistence nature (Windmeijer and Andriesse, 1993). A great diversity of farming types exist with the specific system and relative importance of livestock and crop rotations being largely determined by rainfall, following a north-south gradient. The humid regions in the south are dominated by cereals (maize, sorghum and millet), legumes (groundnut and cowpea), cotton and root crops (yam and cassava). In these regions, the tsetse fly largely limits cattle to indigenous breeds with trypanosomiasis resistance. These breeds are considerably less productive in terms of meat and milk production than exotic breeds (Hursey and Slingenbergh, 1995) and generally too small to use for draught power. Moving northwards, where rainfall decreases to 600 mm/year at the limit of the Sudan Savanna, sorghum, millet, groundnut and cowpea are the principal crops. Cattle farming and animal traction are more prominent due to reduced tsetse pressure, though forage availability becomes limiting due to low rainfall.

Fallow systems are characteristic of Sudan Savanna farms with shifting cultivation practiced in the south and (semi-) permanent systems in the drier North (Windmeijer and Andriesse, 1993). Fallows function as the primary means of restoring soil fertility after several years of cropping. Fallow periods in recent years have become shorter in response to population, economic and trade policy drivers (Barbier, 2000) with the result that shrub and woody species have largely disappeared, soil fertility has declined (Nye and Greenland, 1960; Sanchez, 1976) and grazing and marginal lands are increasingly used for cropping (De Ridder et al., 2004). However, experimental trials demonstrate that the decline in soil fertility is initially rapid following land clearing, but the decline associated with continuous cropping is much less rapid and hard to detect in the short term, and spatially and temporally variable dependent on farmer cropping choices, which in turn depends on market opportunities to enable intensification (Prudencio, 1993; De Ridder et al., 2004); moreover, in a review of regional scale nutrient balances, Powell et al. (2004) do not find evidence of long term decline in soil quality under increasing livestock densities. The lack of strong evidence for a decline in soil degradation with continuous cropping on West African Sudan Savanna farms may be partially explained by spatial patterns of cropping and management intensity employed by farmers (Prudencio, 1993).

The transition from fallow-based towards a mixture of fallow-based, permanent and other cropping systems (Savadogo, 2000; Ouédraogo, 2004; Kanchebe, 2010) has been accompanied by a southward shift of the ecological zones with the corresponding changes in the cropping systems (Aihou, 2003).

Drought tolerant crops such as cowpea, groundnut millet are grown in the uplands while sorghum, maize and root crops are common in the deeper heavier soils near the bottom of the slopes with rice found in the valley bottoms (Windmeijer and Andriesse, 1993). This strategy plays a dual role, of diversification and adaptation minimizing the risk of complete crop failure in the occurrence of extreme weather conditions.

The second spatial pattern is related to the distance between the household and fields and sometimes described as a ‘concentric ring’ pattern, where three types of agricultural land are defined: compound land, family land and bush land (Prudencio, 1993; Laube, 2007). The compound land is closest to the homestead, receiving household waste and the largest share of manure as livestock are kept in enclosures close to home at night. It generally has the highest soil organic matter content and fertility and is cropped most intensively, often with early maturing cereals, what is supported by evidence from Burkina Faso that suggests that some indicators of soil fertility improve under continuous cultivation as compared to land under long-term fallow (Prudencio, 1993). In the family land, fallows are employed and intercropping predominates as the application of manure is sparse. The bush lands are generally large and mainly used for grazing, though fallowing is still a more common practice (Prudencio, 1993; Bationo et al., 1996; Ouédraogo, 2004).

Farms are generally small and crop production for household consumption, except for cotton production, which is subsidized to varying degrees in Benin and Burkina Faso. In the western part of Benin, half of farms are smaller than 1.25 ha, while 50% of the farms cultivate cotton and also have large livestock herds (Igue et al., 2000). In the Upper East Region of Ghana, 70% of the farms vary from 0.5 to 2 ha; the average size of a compound farm there is 1.3 ha for a family of 8 persons. Including the bush land, average farm size was 2.4 ha in 2001 (Laube, 2007). These small farm sizes suggest strong pressure on land and land fragmentation, which are correlated with depletion of soil fertility (Yilma, 2006; Eguavoen, 2008).

Plantation of trees and shrubs is not common, as, 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).

The constraints to increasing yield levels and improving yield stability are complex, involving an interplay of biophysical and socio-economic factors (De Ridder et al., 2004). Rainfall variability is a key cause of yield variability, and droughts and floods can result in crop failures. Animal productivity is limited by the tsetse fly in the more humid areas, with the resulting lack of animal traction constraining cereal intensification and favoring root crop production (Hursey and Slingenbergh, 1995; Dixon et al. 2001). In the drier regions, fodder quality and quantity is generally very low (Kassam et al., 2010) and in some cases insufficient to sustain current livestock numbers, contributing to degraded soil quality and conflicts between crop and livestock farmers (Deng, 2007). The main constraint to increasing crop productivity is poor soil fertility, which declines with decreasing fallow periods. While intensification via fertilization is recognized as a critical element of improving the fertility status of many soils in West Africa (Vanlauwe and Giller, 2006), it is unlikely to be sufficient in the highly degraded soils (Kaizzi et al., 2006) and high temperature regime of the region. Practices to increase soil organic carbon levels are thought to be critical (Swift and Shepherd, 2007), though building soil organic carbon up by leaving soil residues on the soil may result in yield depressions on the short term as most of the crop residues (maize, sorghum, and millet) have very high CN ratios and may immobilize soil nitrogen (Giller et al., 2009). A meta-analysis of the impacts of residue retention and no tillage on cereal yields in Southern Africa revealed benefits of these technologies only for N fertilization rates of 100 kg/ha and greater, levels prohibitive for many farmers in the Sudan Savanna (Rusinamhodzi et al., 2012). Further, a study on sandy soils in Togo revealed that retaining crop residues on the soil, even with high nitrogen fertilization, was not sufficient to arrest declines in soil organic carbon stocks (Kintché et al., 2010). Finally, residues use for animal fodder may be more important for food security as animals serve as insurance against bad weather conditions, expected to worsen under climate change. Additionally, livestock and livestock keeping also have a cultural function, and tenure status may prevent farmers from disallowing animals to graze the crop residues in any case.

Cropping systems

In general, cropping systems include monocrops, permanent intercrops and mixed farming, and lands under temporary intercrops in rotation with fallows, all largely 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 largely 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 seeds, animal and mechanical traction), weak extension services, poor transport and communication infrastructure, with the resulting strong orientation towards subsistence production (Yilma, 2006; Kpongor, 2007; Ntare et al., 2007; Schindler, 2009).

Maize (*Zea mays*) was introduced in West Africa by the Portuguese in the 16th century, and has since gained importance and found its way into the traditional agricultural systems. In the Sudan Savanna, maize is usually grown in intercrop with legumes, usually groundnut or cowpea. It is also grown in combination with sorghum and millet, though its cultivation area is increasing at the expense of sorghum, millet and rice (Sallah, 1992). Maize cultivation is demanding with respect to nitrogen, phosphorus and soil organic matter, and for this reason it is cultivated on virgin lands, and can lead to the rapid nutrient depletion of the fragile Sudan savanna soils, and shortening of the fallow period (Aihou, 2003).

Sorghum (*Sorghum bicolor*, *Sorghum vulgare*), commonly called ‘guinea corn’ or ‘red millet’, is widely cultivated. It originated in eastern Africa where its major variability can be found. Accordingly, sorghum has developed various morphological and physiological adaptations, such as drought resistance. It performs well at rainfall levels (400 to 600 mm/year) too low 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 producers worldwide (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, 2007).

The cultivation of sorghum, maize and millet is important for the provision of carbohydrates to the local diet, and also because of its straw for fuel and foliage as feed for animals. Their cultivation is strongly influenced by local traditions. In northern Ghana, it is considered an exclusively male activity (women focus on groundnut, rice and vegetables), and subject of rituals (Eguavoen, 2007).

Groundnut (*Arachis hypogea*) is the main legume cultivated in the Sudan Savanna and, together with other leguminous species, makes large contribution to fulfilling the protein demand of the local population (Marfo, 1992) and the provision of high quality fodder for livestock (Slingerland, 2000). Groundnut is a preferred legume due to its ability to produce well under soil-moisture-deficient conditions (Marfo, 1992), as well as being 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, with yields declining (Williams, 2002). Aflatoxin is considered the major constraint to its cultivation through its potential harmful effects on human health. Other important legumes include bambara bean (*Vigna subterranea*) and cowpea (*Vigna unguiculata* L.), both indigenous to West Africa, and pigeon pea (*Cajanus cajan*) originally from 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, cotton (*Gossypium hirsutum*), has received wide attention from the African governments, especially in the Benin and Burkina Faso (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 (The World Bank, 2004; Gray, 2005). However, it is suggested, for the case of western Burkina Faso, that this intensification, although more profitable than traditional practices, has led to the decline of soil physical

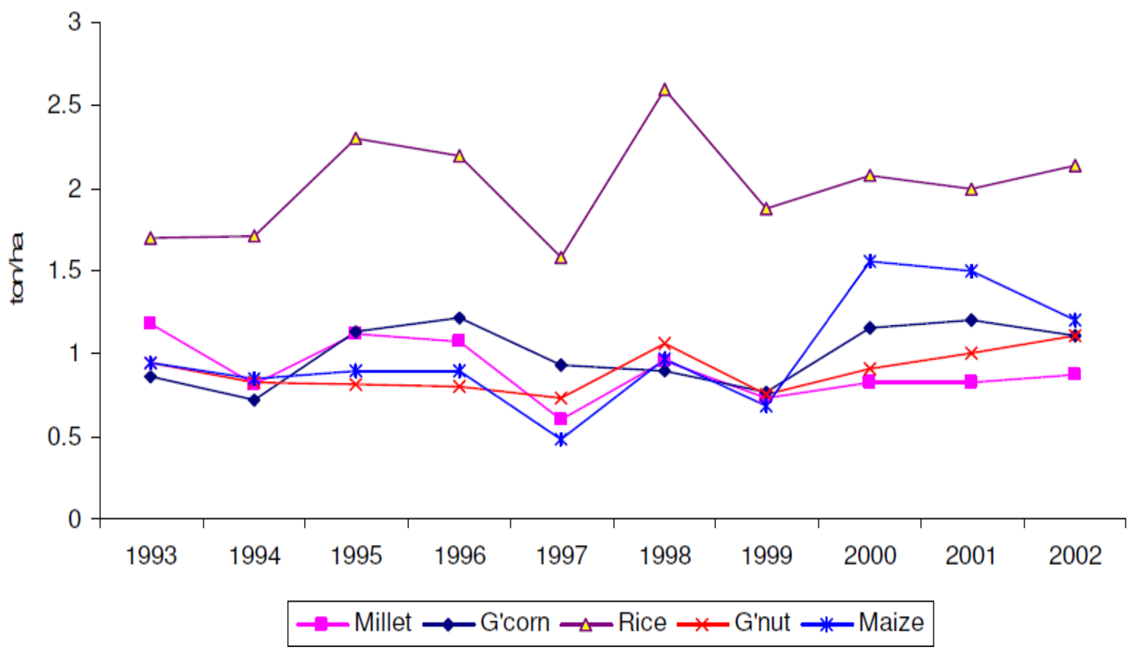

Figure 3. Average annual yields of main crops in the Upper East Region, Ghana. Source: Yilma (2006).

and biological fertility and environmental degradation (McCauley, 2003; Ouattara, 2007). 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).

The evolution of total cultivated area in the region has been a response to 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. 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. In Burkina Faso, cotton production has grown continuously since its installation in the 1950s, associated with expanding areas (Ouattara, 2007). At the southern limit of the cereal-cotton zone, where forest and savanna reserves host virgin and fertile land, the boom in harvested area is continuing, with fluctuations in areas due mainly to water availability of the rain fed crops (sorghum, millet, maize, cotton, groundnut and cowpea), which depend on the monsoon and have considerably higher risks. However, a stagnation situation is observed in the areas for sweet potatoes and yam, and in rice has fluctuated relatively little as it is an irrigated crop (Sanfo, 2010).

Yield, the most important proxy of land productivity, reveals the limitations and uncertainties that farmers face with low yields characterizing the region. As an example, in 5 villages in Northern Ghana, average yields of 0.9, 0.7, 0.7, 0.2 and 0.4 tonnes/ha were reported for maize, sorghum, millet, cowpea and groundnut, respectively (Diehl, 1992) with great variability. The variations are attributed principally to ecological and managerial limitations with combinations of soil qualities, cropping techniques, crop varieties, etc., explaining the variation. For example, high annual yield variability of three main cereals in Burkina Faso between 1984 and 1994 is explained by highly variable rainfall (Savadogo, 2000). Similarly, Yilma (2006) reported large variability in annual average yields of maize, sorghum, millet, rice and groundnut for the Upper East Region of Ghana between 1993 and 2002 (Figure 3). 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.

In many cases, it is not possible to explain such large variations with a single variable but rather on the interaction of a number of variables. Kanchebe (2010) compared the yields of millet, sorghum and groundnut in two moderately wet seasons (1987 and 1989) against two very wet seasons (1999 and 2003) and did not find conclusive matches between yields and rainfall. Similarly, Singerland (1992) could not determine a single explanatory variable in grain and straw harvests of sorghum and cowpea for two rainfall conditions in southern Burkina Faso. Together with rainfall and soil water storage capacity (Allen et al., 1998), the duration of fallow is important in determining yield levels, as the low rates of fertilizers use renders soil fertility highly dependent on fallow regeneration (Gaiser et al., 2010).

Table 1. Average crop yields in relation to intercropping system, slope and planting density in Burkina Faso in 1982 and 1983.

Parameter	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).

Despite the high annual variability, a regional trend of increased production (1 to 8%) is observed between the periods of 1988–1990 to 1998–2000 for the main West African crops, attributed to a combination of land expansion and increasing crop productivity (FAO, 2004).

Intercropping involves planting different crop species and varieties together and is used as a strategy to minimize risk of loss, as different crops/varieties have different water demands and phenological timing in the event of adverse rainfall patterns. It also likely reflects cultural norms of division of labor between women and men (Saidou et al., 2004; Laube, 2007; Eguavoen, 2008). 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 multi-crops, and 50% to the combination of cereals and legumes.

In the Upper East Region of 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 results of an evaluation of yields of the most widespread combinations of cereals and legumes performed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Kamboinse, Burkina Faso are presented in Table 1. The study considered land type, slope, plantation density and time of plantation, and found divergent impacts (Tenkouana et al., 1992).

However, a declining trend of intercropping systems in favor of monocrops has been noted in some areas. In the Upper East Region of Ghana, the percentage of polycultures decreased from 56% in the 1991/1992 season to 45% in 1998/1999. In the same period there was an increase in the proportion of cropland under rice from 1.5 to 14%, though it was predominantly in small plots with a maximum size of 0.25 ha (Ghana Statistical Service, 2000).

Management

As noted above, mixed cropping predominates in the region. The cropping calendar starts in May/June as a function of the onset of the rainy season. Cereals (early millet, sorghum and late millet) are sown in association with legumes, e.g. groundnuts which is planted a few weeks later. Labor distribution is gender specific. Men focus on cereals and women on legumes or vegetables. The latter mainly cultivate in the surroundings of the compound house (Laube, 2007; Eguavoen, 2008). Planting, weeding, and tilling are mostly done manually. The major decision drivers for deciding planting times are rainfall distribution and availability organic matter (manure, residues, compost, etc.).

Nutrient balance is accepted as being negative due to both: export of nutrients through harvest, removal of crop residues, leaching and erosion, surpassing inputs via fertilizers and the growing pressure on land reducing fallow periods (Stoorvogel and Smaling, 1990; Tilander, 1996; Tossah, 2000; Kpongor, 2007).

Stoorvogel and Smaling (1990) estimated the mean net loss of nutrients per hectare cropland was 22 kg/ha of N, 7 kg/ha of P and 18 kg/ha of K per year. While in northern Ghana 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 for maintaining soil nutrient status (Sedogo et al., 1992). Kintché et al. (2010) found that retaining crop residues on sandy soils in Togo, even with high nitrogen fertilization, was not sufficient to arrest declines in soil organic carbon stocks.

However, there is an inherent difficulty to quantify nutrient balances on farms as the estimation of input variables such as deposition, biological nitrogen fixation and sedimentation, as well as output variables: leaching, denitrification and erosion is associated with high uncertainty (De Ridder et al., 2004). Therefore, a further challenge is to more accurately estimate farm nutrient balances despite the high spatial variability in management with the concentric ring system, in which farmers maintain gradients of soil fertility levels as appropriate to their management objectives. For example, in the compound fields, farmers may choose to cultivate early maize in small fields to shorten the duration of the hunger season, instead of planting higher productivity and longer season varieties of maize and sorghum which supply the bulk of household's annual staple food or finally, large areas of millet or sorghum requiring little inputs to maximize yield in a good year – even at low productivity (Prudencio, 1993).

The application of inorganic fertilizers and organic amendments is seen as key to stabilize production and increase yields. 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 9 kg/ha (FAO, 2004). This is due to the high cost of fertilizers (2 to 6 times than elsewhere) (Sanchez, 2002), limited product market opportunities (De Ridder et al., 2003), but also to the limited response of crops to fertilizers due to the varied soil conditions in combination with low rainfall and/or erratic rainfall patterns (Kpongor, 2007) and inappropriate application practices (Igue et al., 2000).

However, exceptions exist as in northern Benin where 75% of the farmers use mineral fertilizers for cotton, since these are subsidized by the government and private companies (Igue et al., 2000). Nevertheless, due to its high cost, it becomes profitable only when used in combination with ploughing, irrigation and a guaranteed product price (Matlon, 1984; Yilma, 2006; Laube, 2007). Small applications of inorganic fertilizers (microdosing) has been tested and shown different effects depending on the crop species, almost doubling yields of sorghum but with little effect on pearl millet (Roth and Sanders, 1984). Also the synergy with intercropping and crop rotation was evaluated, finding good yield responses and use of remnants in subsequent seasons (Schmidt and Frey, 1992). When time considered (area*time equivalent ratio; ATER), intercrops productivity is higher compared to monocrops but not to rotations (Härdter, 1989).

Concerning other fertilization sources, phosphate rock use is common in Togo because of their large maritime deposits. Field studies assert that their use has high residual effect compared to soluble fertilizers (Tossah, 2000). Compost application have considerable effects on yield depending on the applied amount, but no significant changes were noted on the soil organic matter content although they can increase the CEC and pH (Ouédraogo, 2004).

Coupled with the negative nutrient balance, inadequate water supply is also a major limiting production factor (Zougmoré, 2003). Hence, irrigation infrastructure is considered as a development strategy. But this is poor and investments in irrigation facilities are low, except on peri-urban horticultural production sites. Although small dams exist, these often malfunction by accumulation of sediments, and technical constraints. Bucket irrigation is common, and pumps are used when the parcels are located near a river bank. The preferred crop is tomato combined with other vegetables. Agrochemicals are complementarily applied (Schindler, 2009).

Livestock plays a multipurpose role in West African agricultural land use systems (Powell et al., 2004). Manure provision, insurance against unexpected events, wealth saving, food provision, traction, inter-house exchange, rituals and dowry payments are 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, 2007; Kpongor, 2007; Laube, 2007).

Nonetheless and despite the low volume of cattle, overgrazing is a regional problem (Kpongor, 2007). The high competition and low fodder production creates pressure on grazing lands, triggering deforestation and the shortening of fallow periods (Igue et al., 2000), which is often worsened by the seasonal arrival of nomad tribes (Fulani) from the northern Sahel with larger flocks (Schraven, 2010). Farmers mitigate this by integrating livestock with cropping systems through the collection, exchange and application of dung and manure, which is relatively successful but, often leads to negative soil nutrient balances. Also, some tribes have developed symbiotic relations, as Mossi, mostly farmers, and Fulani, mostly herders, who exchange labour for farming and herding activities according to climate and market seasonal demands (Slingerland, 2000).

Understanding the relationships between crop and livestock farming and land degradation is difficult though some research suggests higher productivity and higher animal density may be supported with combinations of better market opportunities (De Ridder et al., 2004), appropriate policy and institutional interventions (Tarawali et al., 2011) and improved access to a variety of animal drawn cultivation implements to maximize labour productivity and better methods of intensifying (secure corralling) to maximize manure inputs (Powell et al., 2004; Wright et al., 2012).

However, the current general performance of these systems is likely not sustainable. Modeling exercises in Zoundweogo province (Burkina Faso) suggest that the nutrient imbalance could only be overcome by increasing the cash availability for optimizing the transport of manure and crop residues, and the purchase of external inputs (Slingerland, 2000).

OUTLOOK

This review asserts that farming and cropping systems of the West African Sudan Savanna are severely constrained by limited soil fertility and scarce water availability, and other complementary factors including limited infrastructure (roads, storage facilities, input and sales markets), lack of access to information and extension services, and increasing pressure on land resources (Valbuena et al., 2012), of which degraded soils and low productivity are the ultimate consequences (Samake et al., 2005).

Accordingly, a number of agronomic options can address one or more of the challenges of poor soil quality, food insecurity and climate variability. Some of the more common include: intercropping and relay cropping, intensification via the use of inorganic fertilizer, crop rotations including legumes, reduced tillage and mulching. Our review highlighted that the retention of soil residues may not always arrest the decline of soil organic carbon levels and questioned the potential of nitrogen fertilization to increase yields on highly degraded soils. The inclusion of legume crops in crop rotations may add a source of nitrogen via both nitrogen fixation and the relatively high N-content of their residues minimizing the impacts of immobilization of soil nitrogen. Conservation agriculture (CA), consisting of minimum tillage; permanent soil cover; and crop rotations, ideally including legumes (FAO, 2008), can maintain yields in lower rainfall years, presumably through limiting soil evaporation and increasing infiltration. However, in extreme drought or wet years, there may be no advantage or even yield penalties of mulching or reduced tillage suggesting that conservation agriculture may not buffer against extreme events (Rusinamhodzi et al., 2011). While irrigation, farming diversification, markets strengthening, etc. require government and/or other institutional interventions (Schindler, 2009), improved soil management technologies may be directly implemented by farmers. However, the evidence suggests that the impact of many of these strategies is highly site-specific dependent on rainfall, soil type and current soil fertility status (Giller et al., 2009; Rusinamhodzi et al., 2011). Further, the benefit of many of these technologies, including those in conservation agriculture, often accrue the most benefits and exceed risk when used in combination, though doing so requires significant initial investment in knowledge and capital – which is usually limiting for smallholder farmers (Nagy et al., 1988).

While it is a critical research question to understand the impacts of reduced tillage, crop rotation and residue retention on soil fertility, the acceptability of the measures to farmers will be evaluated within a framework of food security that may preference livestock to soil quality. Crop growth models responsive to and tested for the key environment, crops and management factors of the Sudan Savanna may be a helpful tool for their evaluation (Kpongor, 2007; Gaiser et al., 2010). Finally, irrespective of their potential to improve food security, farmers' ability to adopt new technologies will necessitate significant policy and institutional support (Nagy et al., 1988).

Increased use of irrigation, promotion of shallow groundwater use and support to community-based water management (Braimoh, 2004; Eguavoen, 2007; Sandwidi, 2007) have great potential to increase and stabilize yields in light of current uneven distribution and reliability of water availability (van de Giesen et al., 2010), and expected future climate challenges related to rainfall variability and increasing temperatures. Some options to effectively meeting these challenges are (i) making better use of inland valleys, (ii) utilizing shallow groundwater resources, (iii) introducing supplemental irrigation, (iv) raising storage capacity with the help of small reservoirs, and (v) combining these strategies. Due to accumulation of surface runoff and interflow from surrounding areas, inland valleys provide an environment less susceptible to rainfall variability (Steenhuis et al., 2003). Use of shallow groundwater and supplemental irrigation (Mdemu et al., 2010; Laube et al., 2012) are key-interventions to overcome or at least to reduce the impact of drought periods on agricultural yield. Under conditions of dry and wet periods expected to become more distinct, small reservoirs are a promising option to serve agriculture and other water uses. Yet, the suitability of these options and their combinations taking the site-specific conditions should be explored, and improvement options designed. Furthermore, the integration of measures into basin-wide concepts and the impact of introducing the above mentioned adaption options on the hydrological situation of the basins and downstream water users and the environmental as well as the socio-economic context needs to needs to be assessed (Johnston and McCartney, 2010).

Adaptation, independently whether it is reactive or planned, is also considered a crucial strategy of local livelihoods to deal with current and forthcoming effects of climate change (UNFCCC, 2007). Adaptation measures can be technological, organizational or managerial; biophysical, socioeconomic, or a combination of them (Smit et al., 2001), but in general all aim at increasing the livelihoods' resilience and diminish their vulnerability to creeping as well as to sudden climatic impacts.

But how farmers configure feasible adaptation strategies? What are the determinants to do so? First, it seems that how farmers conceive climate change defines greatly how they are going to shape their responses (Cannon and Müller-Mahn, 2010); secondly, farmers innovate constantly, proposing new adaptation measures and experimenting them in real conditions (Lybbert and Summer, 2012); and thirdly, depending on performance, the most suitable innovations are incorporated into their consuetudinary activities. In this context, understanding the interdependent processes of how climate change is locally perceived, which are the major determinants of innovativeness; and, once coping measures have been adopted, what is the contribution of these measures to increase livelihoods' resilience, are fundamental questions to disclose climate change adaptation strategies of farmers.

The formulation of political strategies to alleviate the most severe impacts of climate change requires a profound understanding of the mechanisms through which smallholder farms and communities are affected. The analysis of climate change impacts on the food supply and in general on the welfare of farmers in the region requires of a detailed assessment of the spatial distribution of cropping activities, associated technologies, weather indicators, and available assets at micro-scale. To this end, data on bio-physical production processes, climate, soil-types, agro-ecological zones, and socio-economic information should be combined to construct zone- and farm-type specific bio-economic simulation models and linked to local and regional food market models in order to take into account the complex socio-ecological settings of the West African Sudan Savanna (Perez, 2009; van de Steeg et al., 2010).

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