Yields and water productivity of rainfed agriculture in the Volta basin

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Content

Cowpea=niébé (Vigna unguiculata)
Au Burkina: champs de case, champs de village, champs de brousse=champs de campement (semble différent dans les EPA , mais il n'y a pas de parcelle de village)?
Au Ghana : kitchen garden, compound field, bush field

INTRODUCTION – objectif etude, contexte, zone etudiee, plan propose, hypothese

I. AGRO-CLIMATIC ZONES AND FARMING SYSTEMS

A. Agro-climatic zones

An agro-ecological zone is a land resource mapping unit, defined in terms of climate, landform and soils, and/or land cover, and having a specific range of potentials and constraints for land use (Food and Agriculture Organization, 1996).

Despite various efforts to characterize the African savannas on the basis of soils (Jones and Wild, 1975; Food and Agriculture Organization -Unesco, 1976), climate (Rodier, 1964; Kowal and Kassam, 1978), vegetation (e.g., Keay, 1959), population densities (Binswanger and McIntire, 1987) and farming systems (Ruthenberg, 1971; Norman et al., 1982), a major problem remains in the development of a unifying concept which integrates the peculiarities of ecologically, agronomically and socioeconomically oriented disciplines (Weber et al., 1996).
We will consider eventually the climatic zones of the Volta basin as they seem to coincide quite well with cropping systems.

1. Description of the Climatic zones

The Volta basin geographic extent ranges from 6.5°N to 14.5°N, and 5.5°W to 2.5°E. In West Africa, isohyets are globally East-West orientated and the basin intersects them from 450 to 1,400 mm. The rainfall gradient is an important characteristic of the basin as it designs the agro-ecological landscape, and rainfall variability is one of the main drivers for agro-ecosystems. The other climatic components (sunshine, wind…) are undoubtedly important but less determinant in this area.

The map on Figure 1 shows the delimitations of the climatic zones and rainfall patterns in the Volta basin (1990-2000). It is based on the global 0.5° grid of monthly precipitations produced by the Climate Research Unit (CRU) (TS 2.1 dataset). It is publicly available for the period 1901–2002, at http://www.cru.uea.ac.uk/.

The determined zones are the Sahelian area (below 500 mm), the Sahelo-Sudanian area (from 500 to 900 mm), the Sudanian area (from 900 to 1,100 mm) and the Guinean area (more than 1,100 mm).

Given the important variability of the rainfall gradient, the delimitation of the zones is not fixed and may shift (see Figure 3).

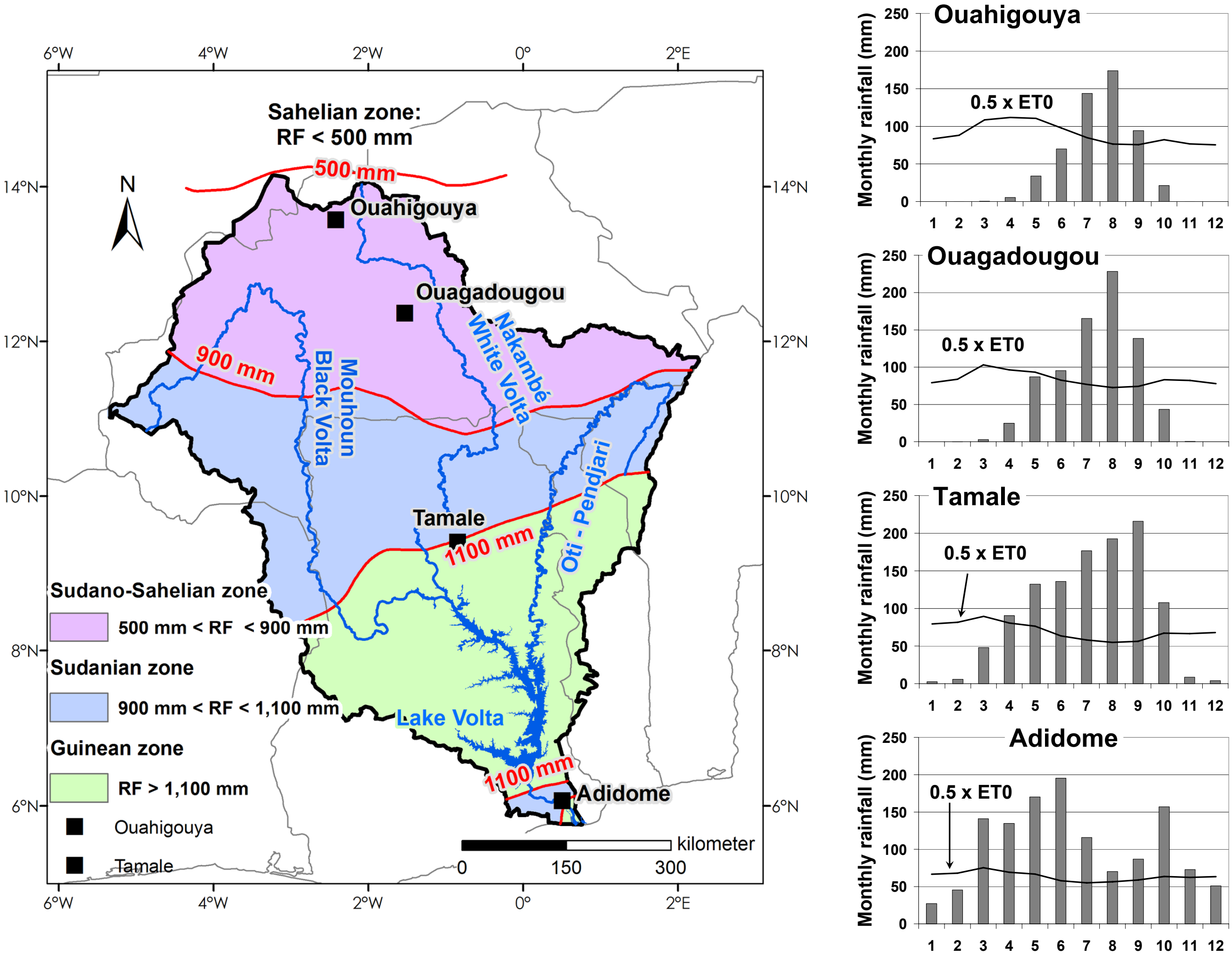

Figure 1: Climatic zones and rainfall patterns in the Volta basin (period 1990-2000, data from the CRU)

2. Climatic constraints: rainfall patterns

Rainfall is the main climatic constraint for agricultural production. The decline observed in West Africa since 1970 (Afouda et al., 2007) has impacted significantly agriculture. In Africa, food production per capita decreased by 1.2 % between 1961 and 1981(Christiaensen et al., 1995). In the 70’s and 80’s the whole Volta basin underwent a rainfall deficit that induced particularly important impact in the north of the basin (Figure 2). In the early 70’s and 80’s (1973 and 1974, and the beginning of the 80’s mainly), Burkina Faso was struck by important droughts, that lead to disastrous consequences including famines, and modified the farming systems (Reij et al., 2005). The 1983 drought also had catastrophic consequences in Ghana: a famine was provoked by the deficit in food production, simultaneously to important bushfires that completely destroyed cocoa plantations and the return of Ghanaians who had emigrated to Nigeria (Dapaah, 1999).

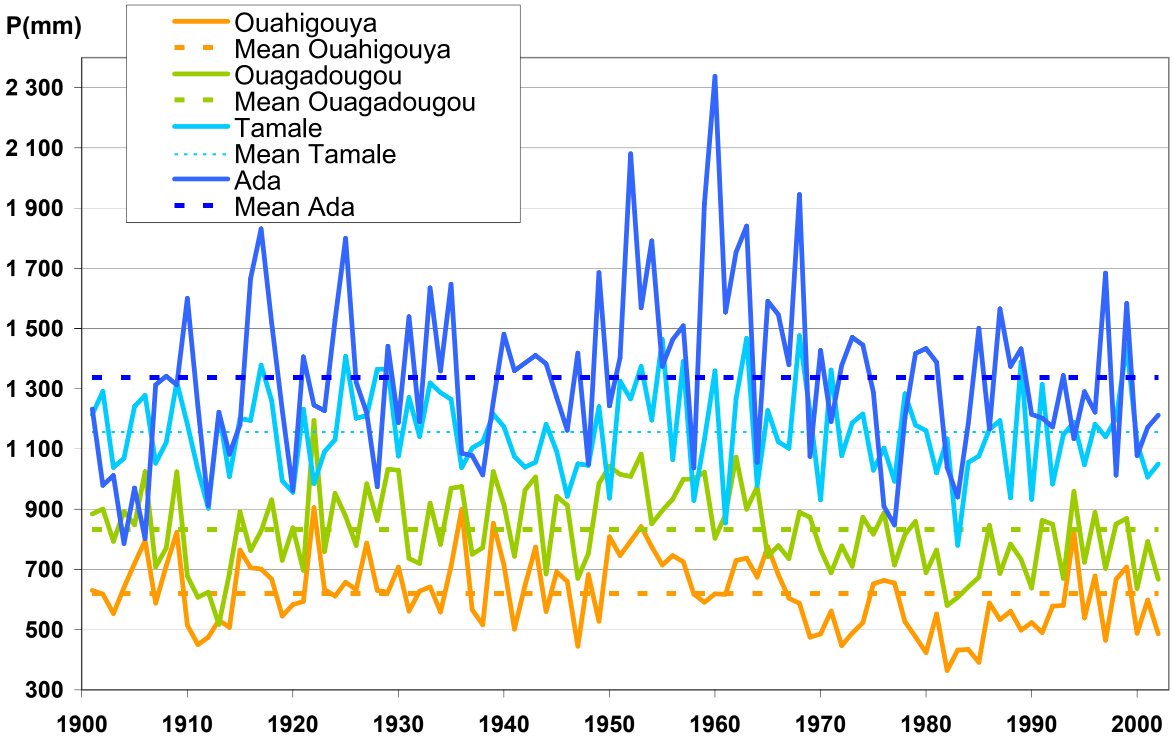

Figure 2: Variability of annual rainfall in Ouahigouya, Ouagadougou, Tamale and Ada between 1901 and 2002 (data from the CRU).

These droughts have been widely described for the Sahel (L'Hôte et al., 2002), but they impacted also the southern part of West Africa. Figure 3 shows that isohyets shifted southwards by about 130-160 km during the last 30 years in the Volta basin (e.g., Sivakumar and Gnoumou, 1987), the total rainfall falling by about 150 mm, leading to changes in distribution of crops, crop varieties and crop management practices (Weber et al., 1996). The number of rainy days also decreased in the same period (L'Hôte and Mahé, 1996; Paturel et al., 1997). Since 1970, some severe dry years have been observed in almost each decade, with significant impacts on livestock, crop production and populations. This water scarcity has been the driver for important change in cropping systems.

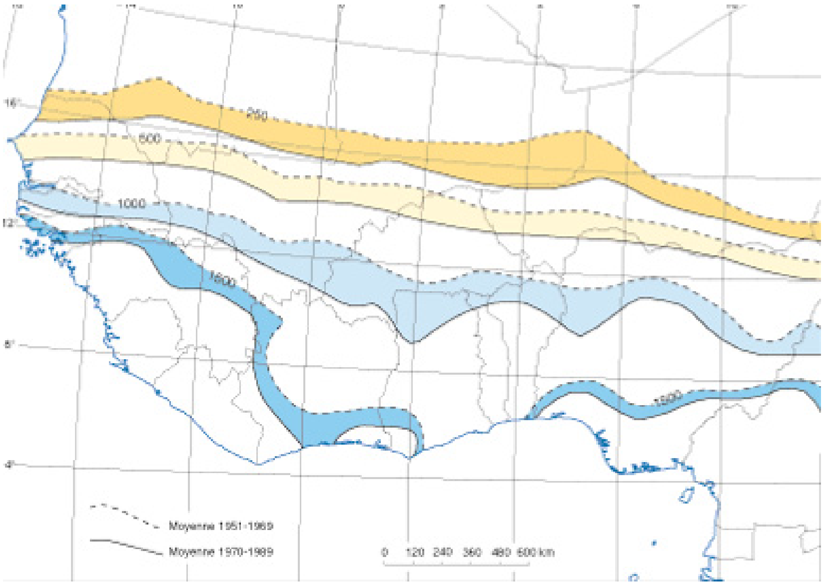

Figure 3: Shift of the isohyets between 1961-1969 and 1970-1989 (L'Hôte and Mahé, 1996).

a) North of the basin

In the extreme north of the basin, the main climatic constraint is rainfall deficit. The climatic context is dominated by aridity and hazard (Milleville, 2006). Rainfall is very variable at any scale considered: both at large and small scale, both at daily and annual timescale.

The inter-annual variability is represented on Figure 2Figure 2: during the last century, annual rainfall varied from 364 to 904 mm in Ouahigouya based on CRU data, with a 1.5 multiplication coefficient between the minimum and the maximum.
The rainfall deficit that happened during the 70's and 80's clearly appears on Figure 2, following 20 years of good rainfall.

The geographic annual rainfall variability is also very high. In the Niamey square degree in Niger, meteorology has been widely studied by *Hydrologic Atmospheric Pilot Experiment* (HAPEX) and *African Monsoon Multidisciplinary Analyses* (AMMA) projects. Studies show that almost every year, annual rainfall varies from a factor of 2 in less than 80 km, with a locally meaningless north-south gradient.

Intra-annual variability is also a characteristic of this area as drought spells often occur after the beginning of the rainy season.

The rainy season is very short, about 3 months in Ouahigouya (Figure 2). PET exceeds rainfall all year except one month during the rainy season. The first rains are stormy, with a high irregularity in their occurrence and intensity. (Milleville, 2006)

A drought refers to annual deficit of rainfall, whereas a dry spell is a punctual deficit of effective rainfall lasting several consecutive days (about 5 at least) during the rainy season. Dry spells impact agricultural production seriously. Thus, annual rainfall can be lower than the mean but produce higher production than the mean if rainfall events are regularly distributed (Milleville 2006). The rainy season is defined by the FAO as the period where precipitation exceeds 0.5 PET (Figure 4))
This terminology will be adopted in the rest of the document.

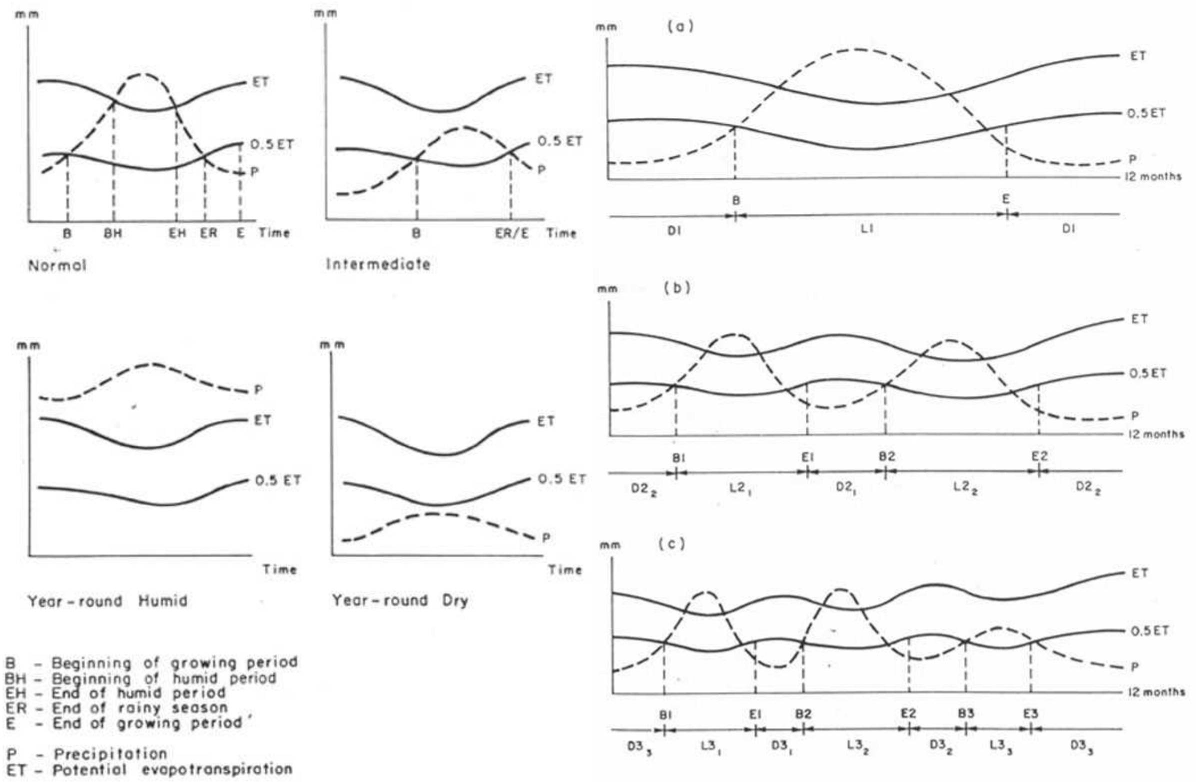

Figure 4: **Schematic presentation of growing period types, number of growing and dry periods per year (Food and Agriculture Organization, 1996)**

b) Median part of the basin

In the median part of the basin, the distribution of rainfall within the year (onset of the rainy season, occurrence of dry spells…) is a major limiting factor. Indeed, the annual rainfall is higher and the rainy season larger than in the North. For instance, the growing season lasts more than 4 months in Tamale (see Figure 4).

The onset of the rainy season depends on the progression of the Inter-Tropical Convergence Zone (ITCZ), and is quite variable. It is an important factor in agronomy. The agronomic rainy season has to be distinguished from the meteorological rainy season. The arrival of the ITCZ and of the first heavy rains defines the onset of the meteorological rainy season, whereas the agronomic rainy season starts when soil is wet enough and rain events become quite regular. According to the date of the onset of the rainy season, different patterns of cultivation will be adopted: for an early onset, farmers will seed long-cycle varieties that produce higher yields, whereas for a late onset, farmers will grow short season varieties to ensure a production.

Annual, monthly and daily rainfall are characterized by high temporal and spatial variation (Sivakumar and Gnoumou, 1987). High rainfall intensities are frequent and result in a high risk of soil erosion (Charreau and Nicou, 1971; Roose, 1977; Kowal and Kassam, 1978; Weber et al., 1996).
The impact of dry spells depends among others on the soil's water storage capacity, on the previous state of filing of this storage and on the growth stage of the crop. The occurrence of a dry spell at the beginning of growing season may kill young plants, but will allow re-seeding afterwards.

c) South of the basin

Further south in the basin, we observe a transition zone between unimodal and bimodal rainy season. This transition is smooth and happens through the augmentation of the frequency of the bimodal rainy seasons when progressing further south. It is a constraint which is quite difficult to cope with and it may explain low population densities observed in these intermediary regions. Agricultural strategies are very difficult to define: farmers don't know in advance the type of rainy season (1 large or 2 short), and the crops they plant may prove inadequate. Agricultural risk of crop failure is consequently very high.

The south of the basin is characterized by established bimodal rainfall. The lower Volta has particularity to undergo bimodal rainy season with each peak insufficient to have satisfying agricultural production. An irrigation scheme is planned in the Lower Volta.

3. Soil constraints

Most African soils are poor compared to most other parts of the world. Lack of volcanic rejuvenation has caused the continent to undergo various cycles of erosion and leaching, leaving soils poor in nutrients (Smaling 1995)

In addition to low inherent fertility, African soils nutrient balances are often negative indicating that farmers mine their soils. Whereas in the developed world, excess applications of fertilizer and manure have damaged the environment, insufficient use of inorganic fertilizer is one of the main causes for environmental degradation in Africa (Bationo et al, 2006).

In the Sahelian zone, soils are dominated by weakly structured sandy soils (arenasoils) and degraded land with bare soils (zipella). In the Sahelo-Sudanian zone, soils are dominated by tropical ferrous soils on sandy-clay or clay-sandy structure. In the Sudanian zone, soils are dominated by eutrophic brown soils (Hauchart, 2007).

B. Characteristics of farming systems

The area is characterized by a rainfed agriculture traditionally orientated towards food production, but that tends to diversify either with the cultivation of traditional cash crops (cotton, groundnut…) or the selling of food crops. Techniques remain quite traditional, with very low levels of mechanization.

Large scale rapid changes in agricultural production and productivity (Green Revolution) did not happen in West Africa. It is rather a large number of small-scale but significant improvements of agricultural production in a vast mosaic of different production systems which have brought change and are likely to continue to do so in the future. The expansion of earth and stone dikes in the Mossi Plateau (Central Plateau) of Burkina Faso (Sanders et al., 1990) is an example of such technologies. They were adopted because they provided clear improvements over existing technologies and because they were compatible with the resource endowments of farmers in the area (Weber et al., 1996).

The practice of **intercropping**, often involving the association of a legume with a cereal, has evolved to become the major cropping system in the tropics. 80% of cultivated land in West Africa is being intercropped[1] (Rose and Adiku, 2001). In Burkina Faso, about 40% of the fields surveyed by the Ghanaian Environmental Protection Agency (EPA) are intercropped, out of which 75% show cowpea as a secondary crop. 30% of intercropped field hosted millet intercropped with cowpea, and 35% sorghum (mainly white) intercropped with cowpea (EPA website). Millet-cowpea intercrop is widespread everywhere in Burkina Faso, except in the rainier Comoe, Hauts-Bassins and Sud-Ouest regions. Rather than sole reliance on single crops such as maize or cowpea, intercropping has evolved as the practice preferred by traditional farmers as a low-input, low-output but efficient cropping system (Rose and Adiku, 2001). However, the relative performance of sole and intercropping systems could alter if even modest levels of fertilizer input were adopted, and could also depend on the climatic zone considered. For subsistence farmers, the most desirable cropping system can depend on their goals of production, which may involve risk minimization and sustainability issues, rather than be based solely on short-term economic factors. Thus economic, social and ecological factors are all important to the adoption, persistence and sustainability of farming systems (Rose and Adiku, 2001).

Since the major research effort worldwide has been on monocrops, research on intercropping is only recently catching up but has concluded on contradictory results.

The droughts of the last three decades have deeply modified cropping patterns. The climatic gradient induces a variety of cropping systems, ranging from cereals-livestock systems in the North to tubers cropping systems in the South.

According to Weber et al. (1996), the most relevant information about a system and its sustainability is related to its evolutionary pathway rather than to its current characteristics.

"Change in agricultural production is primarily driven by the demand for useful products either from increasing food requirements of farming households or from increasing opportunities for marketing agricultural products, both of which are likely to increase in the future. The two sources of demand result in two broadly divergent evolutionary pathways of land-use intensification: population-driven and market-driven." (Weber et al., 1996).

"Each pathway, in its early stages, passes through a land expansion phase when population densities are low, and production is increased through expanding the area under shifting cultivation. However, upland fields have to be fallowed for 8-12 years after 2-4 years of cropping in order to fully restore soil fertility (Jones and Wild, 1975; Pieri, 1989). As the land frontier is reached, the production system gradually enters the intensification phase. Thus, four agricultural domains can be roughly differentiated.

- Population-driven systems in the land expansion phase (PE). The need for food for the household determines the level of production and new land is placed into production as population density increases.
- Population-driven systems in the land intensification phase (PI) are similar to PE, but the land frontier has been reached. Land use intensification goes beyond a level at which natural fallow could restore soil fertility.

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[1] Yields are thus difficult to compute relevantly. In Burkina Faso EPA statistics, a distinction has been done between sole cultivation and intercropped (principal and secondary). We considered yields for sole or principal cultivation.

- Market-driven systems in the land expansion phase (ME) have access to input and output markets. Farmers' choice of technologies and crop management practices are partly determined by marketing opportunities for farm products.
- Market-driven systems in the land intensification phase (MI) are similar to ME, but the land frontier has been reached. Farmers increase their investment into maintenance and improvement of land productivity." (Weber et al., 1996).

Table 1 : Characteristics of agricultural systems under population-driven (PE) or market driven (ME) expansion or under population-driven (PI) or market-driven (MI) intensification. (Weber et al., 1996)

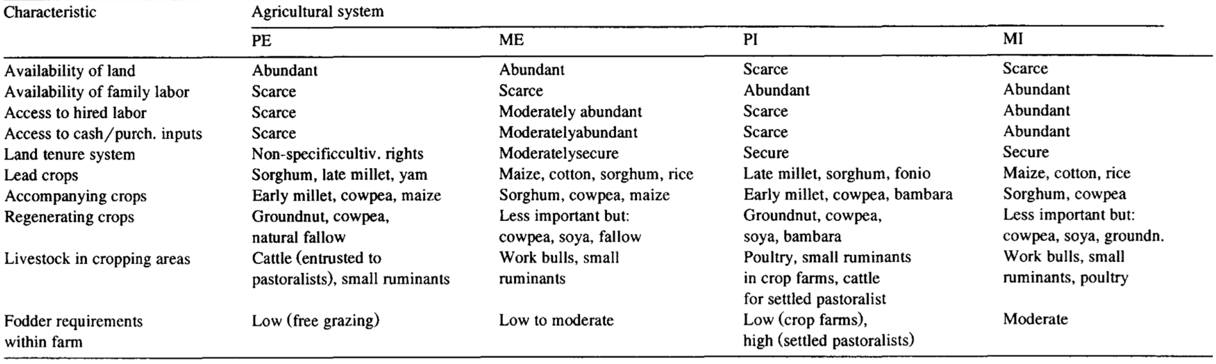

Table 1

Characteristics of agricultural systems under population-driven (PE) or market-driven (ME) expansion and under population-driven (PI) or market-driven (MI) intensification

Characteristic	Agricultural system			
	PE	ME	PI	MI
Availability of land	Abundant	Abundant	Scarce	Scarce
Availability of family labor	Scarce	Scarce	Abundant	Abundant
Access to hired labor	Scarce	Moderately abundant	Scarce	Abundant
Access to cash/purch. inputs	Scarce	Moderatelyabundant	Scarce	Abundant
Land tenure system	Non-specificcultiv. rights	Moderatelysecure	Secure	Secure
Lead crops	Sorghum, late millet, yam	Maize, cotton, sorghum, rice	Late millet, sorghum, fonio	Maize, cotton, rice
Accompanying crops	Early millet, cowpea, maize	Sorghum, cowpea, maize	Early millet, cowpea, bambara	Sorghum, cowpea
Regenerating crops	Groundnut, cowpea, natural fallow	Less important but: cowpea, soya, fallow	Groundnut, cowpea, soya, bambara	Less important but: cowpea, soya, groundn.
Livestock in cropping areas	Cattle (entrusted to pastoralists), small ruminants	Work bulls, small ruminants	Poultry, small ruminants in crop farms, cattle for settled pastoralist	Work bulls, small ruminants, poultry
Fodder requirements within farm	Low (free grazing)	Low to moderate	Low (crop farms), high (settled pastoralists)	Moderate

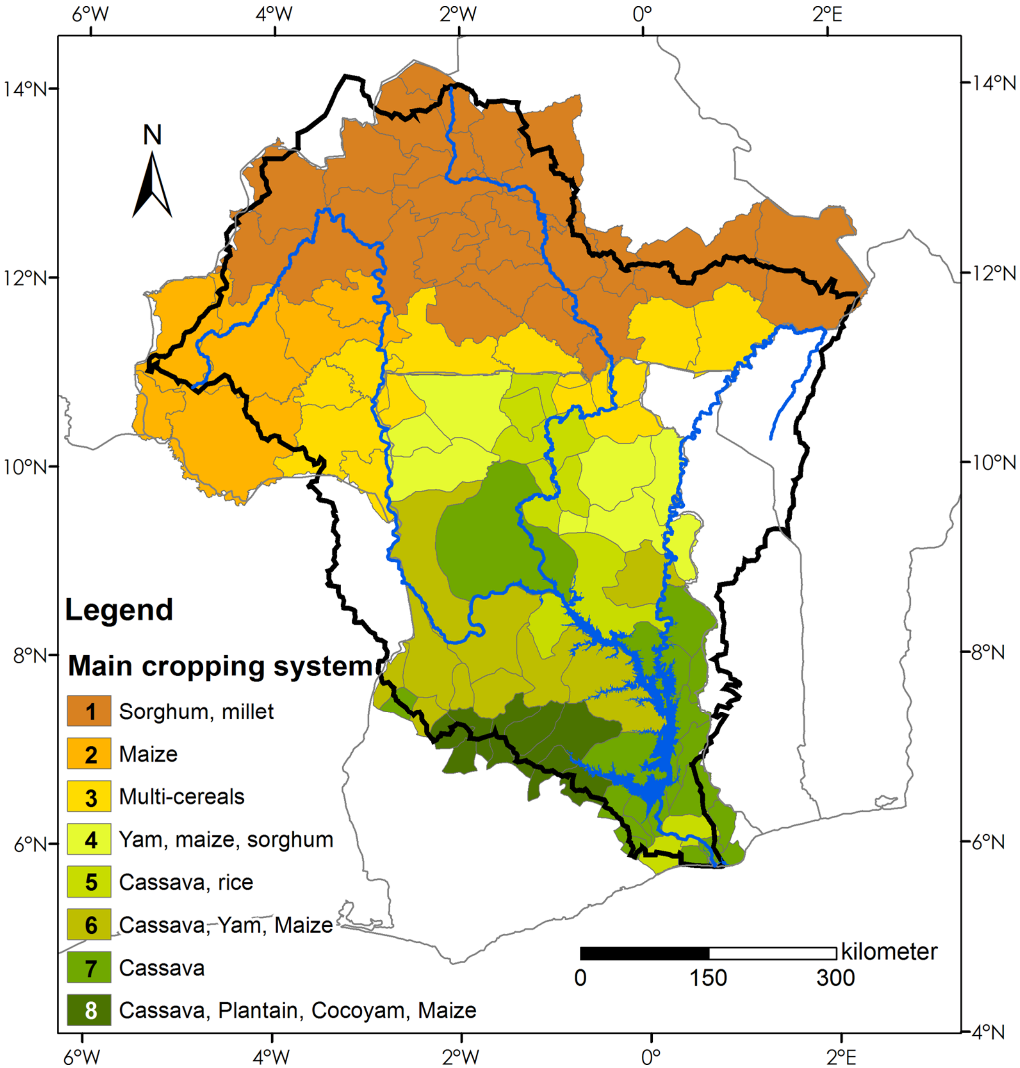

Figure 5: Main cropping systems of the Volta basin (period 1992-2000, data from MAHRH and MOFA converted into energetic content – in kcal).

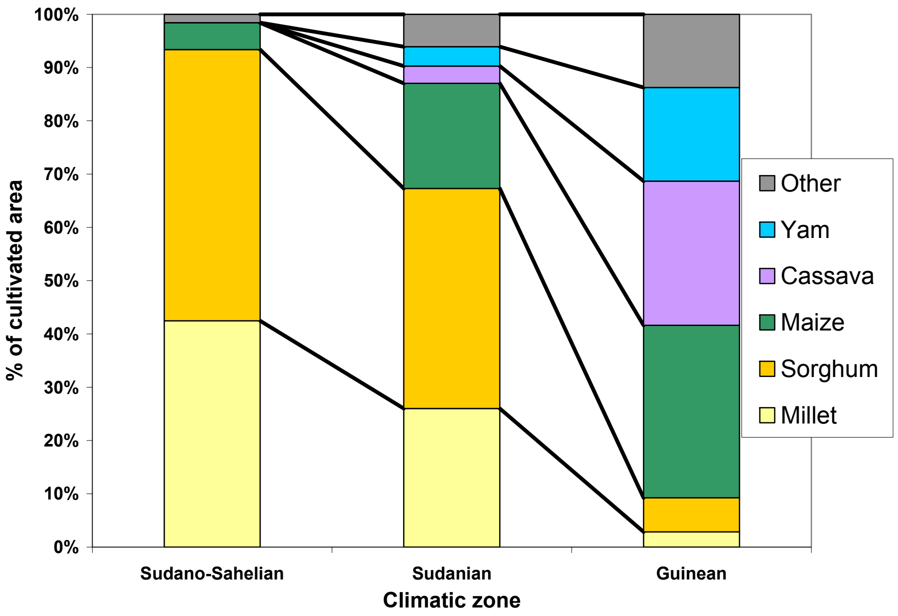

Figure 6: The North-South gradient in food production

a) Sahelian area: agro-pastoralism (Figure 5: system 1)

Though this area is at the northern border of the Volta Basin, sometimes it may cover a larger area as the inter-annual variability of the rain gradient is important.

In the Sahelian area, short-cycle varieties of millet are cultivated extensively (as it is drought resistant) in association with cowpea (*Vigna unguiculata*), in agro-pastoral systems, with mainly transhumant cattle.

Seeding occurs as soon as the first effective rain falls, since early seeding limits the risks of water stress at the end of the crop cycle. The risk of crop failure for early seeding is very high as rains are much fractionated at the beginning of the rainy season. The risk for having a dry spell is the highest in June. Practically, the cost of labor and of low density seeding allows re-sowing in parts of the fields that have undergone important water stress. After an effective rainfall (around 20 mm), farmers dispose of a very short time to seed (about 2 days), as the elevated temperatures sear the soil. Seeding has to cover the largest surface in the shortest time: the whole household is mobilized, and the seeding is done with no preliminary tillage, and seeds gathered in a pocket (5,000 to 6,000 per hectare). These crop practices are simple, without inputs and require little labor. The aim of these systems is to optimize time which is the limiting resource, and to make the best use of climatic events and of the briefness of favorable periods (Milleville, 2006).

Agriculture around Fada N'Gourma remains traditional with low levels of animal traction and a high family labor force per hectare. However, food sales may be higher than in the most intensive region (Dedougou) because of animal products. But farmers also suffer more regular food shortage and they have to buy food more frequently.

The production of millet and cotton tend to increase significantly, while the production of rice and white sorghum tend to decrease massively. Slight increase in animal production, fruits and vegetables, sesame, maize and red sorghum has also been observed (Ducommun et al., 2005).

b) Sudano-Sahelian area (Figure 5: systems 1, 2, 3)

Climatic risk decreases when going further south. Sowing dates are spaced out, but early seeding remains the best way to obtain high yields (when farmers seed early, they can plant a long cycle variety with higher mathematical expected values of yields). One of the main constraints becomes invasion by weeds. Weeds control can be done either by tillage (getting rid of weeds already grown at seeding, which is most efficient for late seeding) or by spacing out seeding in order to space out the following hoeing/weeding, which is crucial but very time consuming. For the farmer, the optimization of its agricultural production corresponds to a good monitoring of all the steps of the production process to avoid weeds invasion.

In intermediary situations, the profile of the beginning of the rainy season will determine the agricultural patterns: if the onset occurs early in the year, farmers will plant long cycle varieties very fast and without tillage, and on the contrary, if the onset is late, land will be tilled and dates spaced out.

In low density areas (and extensive cropping systems), farmers don't try to optimize yield, but their labor, as land is not the limiting factor. This is made possible by extensive cultivation, with lower yields, lower expenditures on larger land (Milleville, 2006).

About 2/3 of farmers in Dedougou and Kaya buy mineral fertilizers, respectively 50 kg/ha and 25 kg/ha, and satisfy respectively 25 % and 60 % of soils needs in organic matter.

Two sub-areas can be distinguished: the cotton (and sorghum/maize) area in the west of Burkina Faso and the mixed cereals zone in the south of Burkina Faso and upper east region in Ghana.

(1) Cotton area (Figure 5: system 2)

Cotton is grown mainly for exports, which requires demanding quality that constrained cropping systems to evolve. Cereals crops remain dominant, but the introduction of a cash crop has favored mechanization development and intensification.

A differentiation of farmers can be done depending on their level of equipment and technique, corresponding to different living standards.

Cultivation is practiced under plantation of *Butyrospermum parkii* (shea tree/"karité") or *Parkia biglobosa* (locust bean/"néré") after burning the weeds.

In farms growing exclusively cereals, manual and traditional practices largely prevail. They feature direct seeding or possibly a manual tilling/scarifying prior to seeding.

In farms cultivating cotton, all cotton fields and the majority of cereal fields are tilled with animal-drawn plough in April or May, after the first rains. Pockets seeding or line planting is done between mid-may and mid-July. Fertilizers (NPK, urea) and phytosanitary products are applied on cotton fields. Fertilizers application depends on bags delivery or re-seeding, and often happens late. Buying NPK fertilizers for at least 3 ha of cotton allow farmers to buy fertilizers for 1 ha of maize. The diffusion of inputs adapted to cotton (NPK and specific treatments) provoked the abandon of cultural associations for monoculture. Fields are weeded with traditional hoe ("daba") 2 to 3 times in July and August. Manual harvest occurs in September/October for maize, October/November for sorghum and December-January for cotton. Residues are left in the field. During the dry season, farmers may build soil and water conservation equipments (see Box 1: Soil and Water Conservation Practices in chapter IV) (Hauchart, 2007).

Crop rotation follows a triennial cycle, maize being planted the year after cotton to benefit from residual fertilizer effect. Fallow periods are still observed, in particular for low input fields, but they are shorter than traditionally (6-8 years after 15 years cultivated), as available land is rarefying.

The increase of income due to cotton cultivation enables farmers to develop animal husbandry, whereas in the meanwhile Peulh herders settle and start cultivating cereals (Pourtier, 2003)

An ethnic differentiation of cropping patterns is noticed: Peulh and Mossi migrants hardly practice fallow. Sharecroppers are not allowed to plant or uproot trees, and don't invest in SWC equipments.

Around **Dedougou,** the intensification has certainly been initiated by cotton cultivation. However, trends in cropping patterns show extension of sesame, maize and red sorghum parallel to a noticeable regression of cotton (Ducommun et al., 2005).

(2) Cereal area (Figure 5: systems 1, 3)

Agriculture relies on extensive cultivation of cereals (Figure 6) and pulses association under tree cover with *Butyrospermum parkii* (shea tree/"karité"), *Parkia biglobosa* (locust bean/"néré") or *Tamarindus indica* (tamarind).

Due to high population density (up to 100 people/km² in the Central Plateau), a transition to intensification could have been expected, but it remained limited eventually (Reij et al., 2005). Despite efforts to modernize agriculture during the 1950–1980 period, in particular the

promotion of cash crops such as cotton and peanuts, animal traction, and sowing on straight lines to facilitate mechanical weeding, farmers adoption of intensification techniques proved to be very partial. Fallow periods have been abandoned and SWC techniques are spreading.
Reij et al. (2005) remarked that the Central Plateau was one of the last regional holdouts for exponents of Malthusian theories. For example, animal-drawn ploughs were used to rapidly expand the cultivated area rather than being used as a tool for intensification (Committee for International Cooperation in National Research in Demography, 2006).

Kaya region shows signs of intensification such as manure application, rice and vegetables cultivation. However, important variations among villages are noticed due to differences in water availability and inland valley valorization. Trends in cropping patterns are not very marked but slight increase in cowpea, fruits, vegetables, groundnut, sesame, white sorghum and rice has been noticed.

In Burkina Faso, 3 types of fields can be distinguished: bush fields (that are far from the village, where farmers settle for a few days when they have to intervene), village fields closer to villages, and “kitchen gardens”. The distinction between bush and village fields does not exist in Upper East region of Ghana.
In bush fields, sorghum, millet and maize are grown associated with cowpea with traditional and manual techniques. Seeding occur either directly or after a light tillage with “daba”. Manure fertilization is neither systematic nor sufficient. From July to August, fields are weeded and plants earthed up to keep the roots wet and avoid rooting up during the windy events of September and October (Kaboré, 1994). The extension of mulching is controversial (Slingerland, 1996) and limited by the lack of agricultural residue that generally feeds livestock. Consequently, farmers have to cut grass in April and May when improper for animal feeding, or tree leaves. After harvest, fields are pastured. Agriculture and animal husbandry appear complementary: farmers with numerous cattle consign it to Peulh, while Peulh tend to settle and start cultivating cereals.
Farmers pay more attention to village fields, eventually tilled with plough, and seeded with a rotation of maize, sorghum or millet in association with voandzou. They benefit from more manure inputs and more SWC equipments. In contrast to the `bush fields', the `village fields' do not require fallow periods but allow permanent cultivation because they are intensively manured by domestic waste and the excrement of small livestock(de Zeeuw, 1997).

“Kitchen gardens” are devolved to vegetables gardening, tobacco and short cycle maize crops grown for the end of the dry season. They receive a lot of organic matter (compost).

In this area, from north to south, a gradient of cropping systems can be observed.
In the north of the area (Figure 5, system 1), millet is widespread as it is resistant to droughts. Peulh animal husbandry more developed than in the south and it appears extensive and semi-transhumant. To cope with water stress, farmers tend to implement water conservation techniques (cf chapter IV). When progressing further south, cereals diversify and include sorghum and maize while the association with cowpea tends to disappear.
The south of the area (Figure 5, system 3) associates cereals with pulses (cowpea, pois cajan) (Padi, 2003) and crops appear more diversified. Cash crops such as cotton or groundnut are introduced, with the corresponding intensifying practices.

(3) Influence of migrations on cropping patterns

A research programme (PRIPODE) held on 3 provinces of Burkina Faso (Kompienga in the cereal area, Poni and Noumbiel in the cotton area) showed that migrations participate in the growth of production and the improvement of household living conditions. However, the absence of security in land tenure as well as the deficiency in environmental legislation can invert the development dynamics.

In both zones, migrants are given fallow land or wild land and tend to cultivate with intensified techniques. Autochthones were used to small fields for foodcrop production, whereas migrants tend to cultivate larger fields and introduce cashcrops such as fruit trees (cashew…) in the South-West/cotton area, or cotton in the East (cereal area). The economic return enables migrants to buy agricultural equipment and fertilizer that improve productivity. Their success starts to create intensification dynamic for autochthones and influences the traditional cropping patterns. It also limits young people exodus.

Other transformations range from the multiplication of permanent markets, with introduction by the migrants of small business and the development of rural employment (diversification of livelihoods, switch towards liberal economy), which is a first step towards urbanization.

c) Sudanian area (Figure 5: system 4)

(1) Crops

Sorghum and millet are the traditional staples while root crops such as yam, cassava, taro, sweet potato and potato are important in some land-abundant areas. This system is quite diversified and provides better guarantees for food security (Figure 6). Agricultural practices are different for cereals and tubers and crop calendars staggered. The relatively abundant rainfall (900-1,100 mm) enables farmers to grow long cycle varieties and short-cycle maize with 2 harvests per year.

Protein is mainly obtained from cereals, legumes and fermented milk products. The spread of maize and cotton has been associated with the development of market-oriented agriculture in the savannas (Weber et al., 1996).

(2) Land and soils fertility

Several types of agricultural land (resource domains) can be distinguished:

- Moderately fertile uplands (Mu) with no or low applications of fertilizers or organic residues; they occur in all four agricultural systems but predominate in particular during the expansion phase in ME and PE.
- Fertile uplands (Fu) of high fertility which may be due to intensive fertilizer use in market-driven systems, especially MI, or to an intensive use of organic residues and the management of soil processes, especially in compound fields in PI.
- Degraded uplands (Du) of low fertility, due to overexploitation of the soil and the lack of soil amendments to restore fertility; such soil conditions become especially important under population-driven intensification. Poor management of soils and unbalanced fertilizer use may cause severe soil degradation in market-driven areas due to soil erosion or acidification.

- Inland valleys (Iv) of varying fertility but hydromorphic soils; the use of inland valleys is labor intensive and becomes more common as systems intensify but further research to classify these areas is necessary.

(3) Practices and intensification

“Sorghum, maize, and cotton-based cropping systems predominate and are complemented by millet and groundnut-based systems. Compared to other cereals, sorghum provides a high land and labor productivity under low levels of external inputs (among others PI scenario). It is a lead crop in areas of extensive land use and remains important as land use intensifies. The early development of the crop canopy provides a niche for early millet which farmers intercrop into traditional sorghum as land use intensifies.

Late millet, which maintains better yields than sorghum under degraded soil fertility, increases in importance in areas of high land use intensity without adequate soil amendments.

The importance of maize increases as soil fertility is improved through fertilizer application, soil regeneration through extended fallow or soil amendments in form of manure or crop and household residues (MI scenarios). For instance, maize is planted on fertile compound fields (village fields) and provides a reliable source of early food, although such areas often constitute only a small proportion of the total arable land area. Where maize is an economically profitable cash crop which pays for the fertilizer and labor, it takes a lead role in the system: market-oriented maize-based systems develop.” (Weber et al., 1996).

Cotton based systems happen in moderately fertile uplands under market driven expansion and intensification.

The term ‘farming domains’ is suggested to classify the evolution of cropping and livestock systems. A farming domain represents specific crop and resource management practices organized around lead crops and also capture farmers’ access to exogenous and endogenous resources. Farming domains therefore constitute an adequate level for most research on crop and resource management and for extension.

Fields are slashed and burnt prior to tillage in March or April; ashes and weeds are buried. Maize and sorghum are seeded from mid-May to mid-July and weeded 2 to 3 times. Tubers require organic matter (residues and manure); plantlets are placed in hoe holes dug on hills previously prepared. From June, weeding and staking are implemented. Harvest happens before sorghum, in September-October.

In bush fields, rotations alternate tubers, sorghum in association with Cowpea[2] or groundnut or bambara peas, and long-cycle maize under plantations of Butyrospermum parkii/Khaya senegalensis/Faidherbia albida/Tamarindus indica. Farmers use SWC techniques to prevent erosion and runoff. Fallow is still more practiced than in the other areas, but it tends to decrease due to demographic pressure. Shifting bush fields tend to settle, but the induced deficit in organic matter is not compensated.

“Home gardens” are cultivated with the same crops as in Sudano-Sahelian zone: early maize, tobacco and vegetables under *Acacia albida*.

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[2] Among the basin riverine countries; Burkina Faso, Mali, Benin are exporters of cowpea, while Ghana, Togo and Ivory Coast are net importers (Langyintuo, A.S., J. Lowenberg-DeBoer, M. Faye, D. Lambert, G. Ibro, B. Moussa, A. Kergna, S. Kushwaha, S. Musa, and G. Ntoukam. 2003. Cowpea supply and demand in West and Central Africa. Field Crops Research 82:215-231. 2003).

Farmers utilize a wide range of crop and resource management technologies such as SWC (stone dikes or tied ridges), methods of residue management for soil fertility improvement.

Ghanaian and Burkinabe sides of the area show differences. Mechanization and intensification techniques (hitched up tillage…) are more widespread in Ghana than in Burkina Faso, since cotton cultivation has been developing from the mid 80's. In the Lobi region, farmers also raise cattle but it is considered as prestigious and not used for ploughing.
Livestock are an important component of the intensification process. Livestock systems shift from traditional pastoralism (fallow and free grazing) to crop residue grazing in the field to finally confinement of animals with most crop residues harvested and preserved as fodder. Animal wastes are then utilized and highly valued as manure for crop production. Animal traction may increase as a source of power for intensive land management. Mixed farming is an evolving phenomenon with a higher incidence of integrated crop-livestock systems in the drier savannas than in the humid zones (Weber et al., 1996).

North Togo areas with high population density typically correspond to PI areas: land is rare, extension of cropland is limited, and soil productivity is low due to insufficient regeneration. The intensification processed is hindered by difficulties to access information on intensification techniques. The working force is abundant, even excessive and the use of fertilizers more widespread than in low density areas. But the very high fecundity index (6.3 child/woman) decreases the annual revenue per capita and deteriorates the livelihoods: 50 % of households are considered as indigent.
In areas with low population density (PE), fields are larger and land productivity is higher. Any increase in the working force contributes to increase yields, resulting in higher living standards. (Comité international de coopération dans les recherches nationales en démographie (CICRED), 2007).

Savings institutions closer to farmers and self-administered credit will be needed to enable transition towards intensification, which requires more investment in agricultural production.

Technical assistance adapted to farmers' needs and expectations is also crucial, above all to provide advice on the best farming techniques. For instance, strip farming seems to be a good and sustainable solution to fight against physical environment degradation in this region. (Comité international de coopération dans les recherches nationales en démographie - CICRED, 2007)

(4) Migrations

"The geographic location of this agro-climatic zone, with its proximity to less favourable arid and semiarid areas to the north, results in immigration into and through the area, particularly to the more commercially oriented systems (Zachariah and Conde, 1981). As a result, population pressure on arable land, wooded areas and grazing land is expected to continue to increase." (Weber et al., 1996). In Togo, important inequality in land distribution and productivity has been noticed among ethnical groups.

In land-rich areas, labor is the most limiting resource, thus labor-productive technologies predominate. As land use intensifies, land productivity becomes increasingly important and land saving technologies such as intercropping, soil improvement and external inputs (in areas of good market access) become important (Weber et al., 1996).

These density variations and subsequent economic inequalities may be reduced by a transfer of the working force that will reduce human pressure in densely populated areas, and increase production in low density ones. (Comité international de coopération dans les recherches nationales en démographie (CICRED), 2007)

d) Guinean area (Figure 5: systems 6, 7, 8)

Most of Ghana’s forest is semi-deciduous, with a small area of high rain forest remaining only in the southwestern part of the country. The staple crops of the forest region are maize intercropped with cassava, plantain, yam or cocoyam (Figure 6).

(1) Geographic distribution

In the medium part of Ghana (6), cassava replaces sorghum, and complements yam and maize.
The central part of the basin, along the White Volta, the lake Volta and the Lower Volta (5) is characterized by noticeable production of rice, as a complement of other staples. Lowland fields along river valleys are the predominant areas for rice production in the Guinea savanna zone. Very little chemical inputs are used in such rain-fed lowland rice farms, primarily because of production risk (e.g., drought and flooding) and financial constraints (Yiridoe et al., 2006).
The agricultural production of the eastern part of Ghana (7) is highly dominated by cassava. The south-west of the basin (8), region where rainfall is highest, has quite a diversified production: cassava, plantain, maize, cocoyam, and yam.

(2) Cropping patterns

Farmlands usually feature a concentric spatial arrangement, with human settlements in the centre. An inner ring of more fertile compound farmlands constitutes an intensively managed area, typically interplanted with maize and/or cowpea and tobacco. These compound farmlands, which are sometimes (erroneously) referred to as ‘‘home gardens’’ in the literature, are usually cultivated annually (i.e., with no fallow periods). Beyond the compound farms lie the bush farms, which may be just a few 100 m to several km away from the family home. The particular form of traditional practice in Ghana intercrops cereals with a leguminous crop (Rose and Adiku, 2001). Upland bush farms may be managed as a rotation of mixed and/or intercropped systems, including tubers (e.g., yam and cassava), cereals (e.g., millet, and sorghum), and leguminous crops (e.g., beans/cowpea, and groundnuts). Lowland fields are generally planted with rice. The above crops, together, constitute more than 90% of the mix of crops typically cultivated in household farms (Yiridoe et al., 2006). This common ``moderate-input / moderate-output" intercrop technology is an efficient cropping system for Ghana (Rose and Adiku, 2001).

Cassava, which is a low input crop with an ability to survive under marginal conditions, constitutes one of the staples in this area. It is essentially consumed by humans, despite its good potential for animal feed in smallholder farming systems (Christiaensen et al., 1995). Use of cassava as animal feed is greater in densely populated areas.

Livestock and poultry are typically raised within the compound farmlands, and constitute an important component of the mixed farm. Cattle production is slowly shifting as a social status symbol and is increasingly becoming a significant component of the household food security and financial risk management strategy (Panin, 1988). In addition, small ruminants (e.g., sheep and goats), pigs, and poultry may be raised and sold to provide cash income or for purchasing food during a lean season (Yiridoe et al., 2006).

(3) Soil fertility

Farmers’ practices to maintain soil fertility are widespread, and depend on ethnical groups. The native farmers who own land tend to use rotations involving long-duration crops such as cassava and pigeonpea to improve their soils. In contrast, migrants who depend mostly on short-term rental or sharecropping arrangements, rely more on rotations with short-duration crops such as cowpea and groundnut to improve soil fertility.

Although farmers recognize the contribution of cowpea to soil fertility and to yield of the subsequent maize crop, they do not consider this as an important criterion when selecting varieties for use in their own fields. The overriding criteria for selecting cowpea varieties are early harvest, seed quality in terms of taste and marketability, and ease of production (low labor demand). Cassava / maize rotation seems to be the most profitable rotational sequence while speargrass fallow / maize rotation seems to be the least profitable. Farmers’ preference for a particular practice is related to accessibility to production resources and livelihood aspirations (Adjei-Nsiah, 2006).

II. AGRICULTURAL PRODUCTION AND YIELDS IN THE VOLTA BASIN SINCE 1992

A. Data used - basin scale the right scale?

Crop production data from the agricultural ministries in Ghana and Burkina Faso have been gathered, compiled, and plotted in GIS. Data include production, cropped area and yields of the main crops for each district in Ghana (period 1992 - 2004),and for each province in Burkina Faso (period 1984 - 2004) (MAHRH, 2006; MOFA, 2006). They have been collected through annual surveys in each district. Some sample farms are randomly selected each year, and sample fields examined. The data are then extrapolated for the whole district/province.

The reliability of national statistics for agriculture has often been questioned (e.g. Milleville, 2007). In Ghana, mean production and yields data of some districts showed significant differences to the 1998 Ghana Living Standards Survey (GLSS). In Burkina Faso, Serpantié (2003) has compared his own observations for yields in the southwestern part of the country with those of the Ministry for Agriculture. He concluded that the official data compared well at the district scale, although they differed at the village scale.

In this work, we have used the official data provided by the MOFA and MAHRH.

Data were mapped in GIS using FAO Geonetwork (http://www.fao.org/geonetwork/srv/en/main.home) administrative boundaries. Values are distributed over Burkinabe administrative divisions as they existed prior to 1996, as agricultural data from Burkina Faso did not consider the administrative changes until 2001. In Ghana, some districts were split in 2005but we mapped the old districts.

The basin boundary has been drawn by the SIEREM (www. hydrosciences.org/sierem). Any district that intersects the basin boundary has been incorporated into the analysis. Its contribution to the total basin production or cropped area has been estimated by pro-rata. Data for other countries (Togo, Mali, Benin and Ivory Coast), which share 17 % of the total basin area, have not been investigated here.

B. Foodcrops

1. Basin production

a) Evolution of production

Starchy food crop production and cultivated area have been increasing in the period 1992 - 2003, with a rate of 2.4 % for cropped area, 4.3 and 3.5 % for the production expressed in tons and calories respectively. These figures become 3.6 %, 5.1 %, and 4.8 % respectively if we include 2004 - 2005 in the analysis. 2005 is considered to be very good year (also relayed in Burkinabe newspapers such as Lefaso.net), but figures of production and cropped area seem too high to be fair. 2004 on the contrary shows a decline in cropped area that seems suspicious (Figure 7). For these reasons the following analysis will focus on years 1992 to 2003.

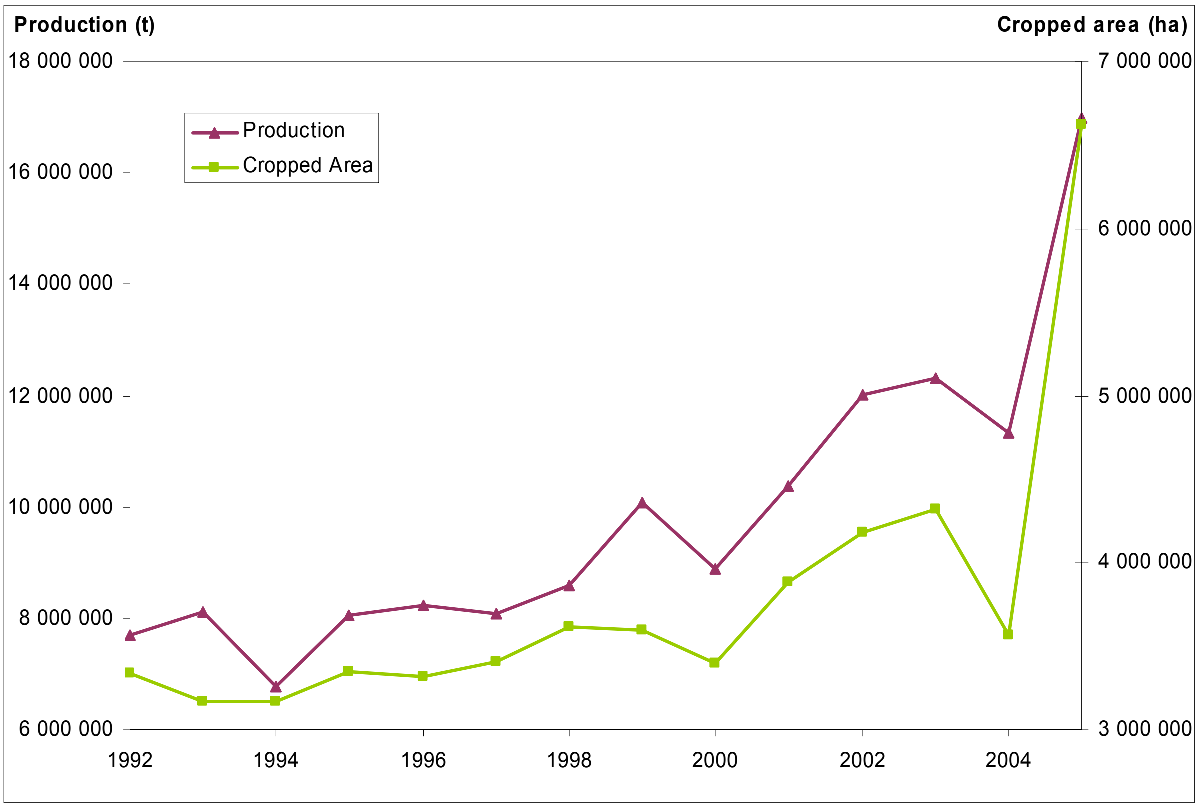


Figure 7 Evolution of the total starchy crops production and cropped area (1992-2005) in the Volta basin parts of Ghana and Burkina Faso (data from MAHRH and MOFA).

The growth rate of production (either in kcal or in tons) can be compared to the annual population growth rate between 1990 and 2000, which ranges from 2.6 % to 3 % (Table 2). Agricultural production grows faster than population.

Table 2 : Population and growth rate in Ghana and Burkina Faso (Source: United Nations population division: http://esa.un.org/unpp)

Population (x1000 pers.)	BF	GH
1990	8 871	15 579
2000	11 882	20 148
growth rate	3,0%	2,6%

Starchy crops production in Figure 7 has been converted into calories to allow comparison between the crops, according to the following conversion table (Table 3).

Table 3Conversion table of crop quantities into calorific content (source . Barikmo et al. (2004))

Name of the crop	Taxonomic name	Calorific content
Fonio		335
Maize		370
Millet		344
Rice	*Oriza sativa*	345
Sorghum	*Sorghum bicolor*	349
Yam	*Dioscorea sp.*	99
Cassava		148
Plantain		137

The increase in production is quite regular for cassava and yam, and more ragged for cereals, as they are cultivated in areas more prone to erratic rainfall (Figure 8).

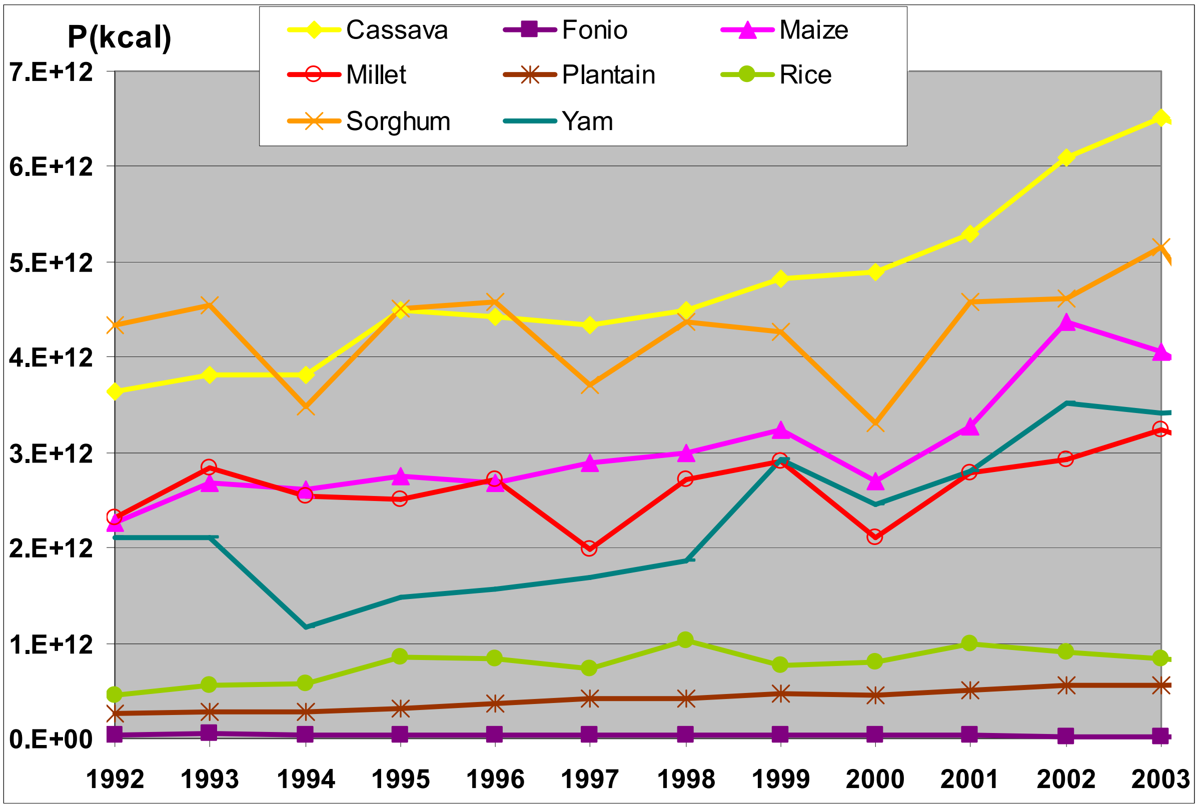


Figure 8: Evolution of the calorific production of the starchy crops in the Volta basin parts of Ghana and Burkina Faso (data from MAHRH and MOFA).

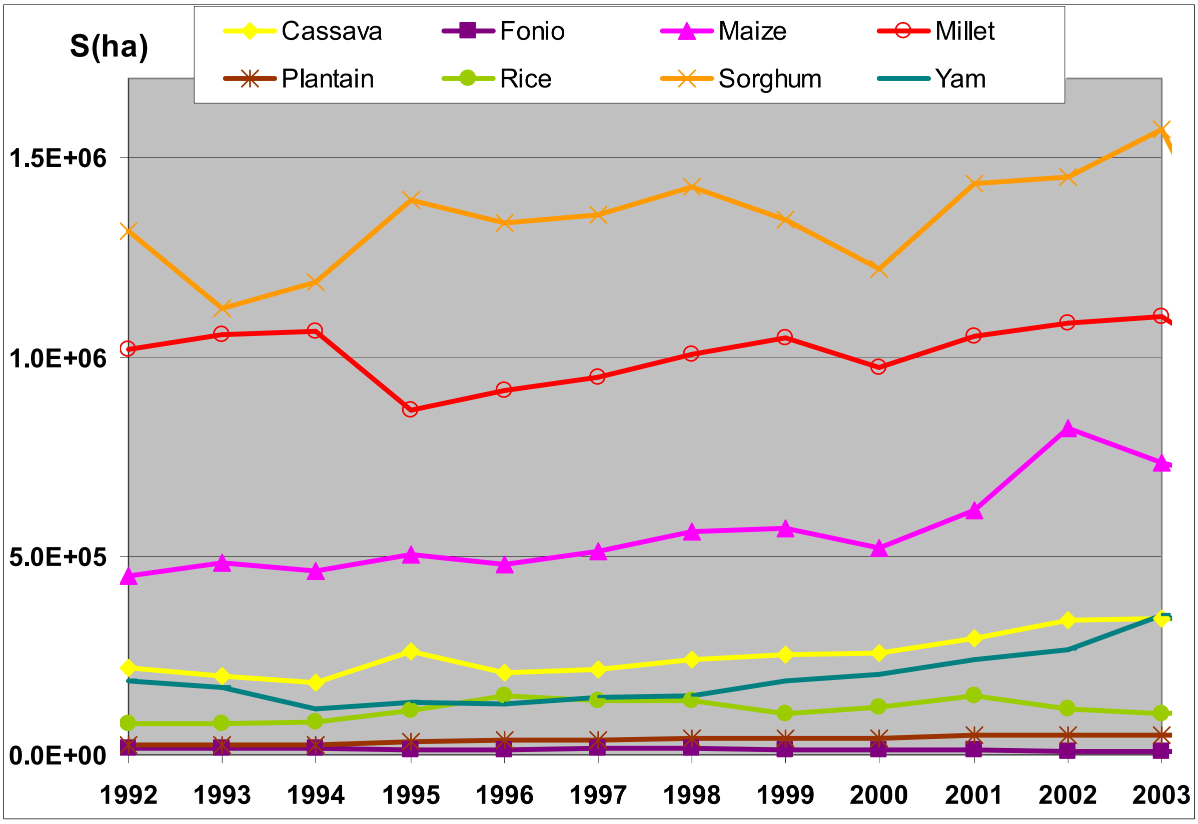


Figure 9: Starchy cropped area (ha) in the Volta basin part of Ghana and Burkina Faso (data from MAHRH and MOFA)

The cropped area figures show a slight and quite regular increase for each crop (Figure 9). In Burkina Faso, 80% of the cropped area is used to grow cereals (www.leFaso.net).

Globally, starchy food production and cropped area increased during this period, but a more detailed analysis reveals nuances. Growth rates for starchy food can be computed with the hypothesis of a linear variation. Some crops have known a significant rise, such as yam which area and production growth rate was respectively 7 % and 6.8 %, plantain (+6 % and +6.7 % respectively), cassava (+4.6 % and +4.5 % respectively) and maize (+4.4 % and +4.3 % respectively). Cocoyam underwent a slight increase (growth rate: +3 % and +2.1 %), while millet (+0.7 % and +1.5 %) and sorghum (+1.6 % and +0.8 %) remained quite stable. Rice yields and growth rate was particularly important (+2.8 % in area and +4.2 % in production). Fonio tends to decrease is quite marked (-3.8 % and -3.7 % per year respectively).

The progression of production during the last 15 years is essentially due to the extension in cropped area, as the production and cropped area growth rates are quite similar. The exception is rice, which yields improved significantly in the last 15 years. This stagnation of yields show either that intensification is not taking place as expected for food production, or that the new fields prepared for cultivation hadn't been cultivated formerly because of their low fertility or, on the contrary, that the fertility of old cultivated land has been eroded due to fallow regression. Reality may be a combination of these three factors.

The regression or stability of drought resistant crops (fonio, millet, sorghum) in favor of water demanding crops could be explained by improving climatic conditions after the droughts of the 70's and 80's. The lasting increase in rainfall (see Figure 2) after the 80's may have modified slowly farmers planting choices, above-all in the north of the basin. Farmers modify progressively their cropping patterns in response to their perception of climate change.

b) Food consumption

If we consider means for the whole basin, the Burkinabe and Ghanaian parts of the Volta basin produce enough starchy crops to feed the whole basin population. With a population of 19.5 millions inhabitants in 2005 (Lemoalle, 2007), the mean total production of 17,450 billion kcal (period 1992 – 2000) corresponds to a daily starchy food intake of 2,800 kcal, when FAO establishes daily needs of 3,000 kcal for a man and 2,000 kcal for a woman (Food and Agriculture Organization /WHO, 1973). Globally, the basin seems barely self-sufficient in terms of energetic production. Table 4 provides 2005 and forecasts data for the population growth with the food needs involved (Lemoalle, 2007).

Table 4 Population and Food Needs (2005 and forecasts)

Year	Population ($x10^6$)	Food production kcal($x10^{12}$)	Food needed kcal ($x10^{12}$)
2005	19,5	17	17
2025	32	?	28
2050	50-60	?	48

With the exception of rice, which consumption exceeds production on the basin and which is imported from Asia, the other starchy food productions seem sufficient to feed the basin population.

This global satisfaction may not be guaranteed at individual level. Indeed, Sahelian zones often undergo food insecurity (Famine Early Warning System of FAO, http://www.fews.net): surpluses in some parts of the basin (or even within countries) are hardly available in markets where it is lacking and food shortages happen quite regularly. The organization of markets in Burkina Faso is not fluid.

In addition to this geographic inequality in distribution, the variability of food availability and prices within a year is very high. A particularly difficult period is the beginning of the rainy season, when the previous year provisions have been consumed and the new harvest is not yet available ("soudure" period). Agricultural prices are thus very high and farmers contract debts in this period (in June, Figure 10). They sell their standing crops to speculators at very low price, which keeps the vicious circle going as they will have neither enough money nor enough food to make ends meet the following year.

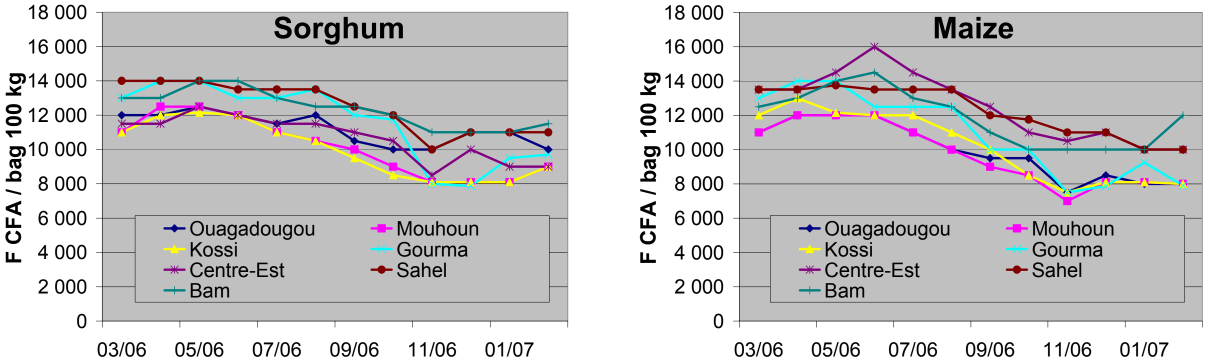


Figure 10: Evolution of sorghum and maize prices from March 2006 to February 2007 in Burkina Faso (Source: bulletins Afrique verte : Situation alimentaire Burkina – Mali – Niger (mars 2006 et 2007), http://www.afriqueverte.org)

Evolution of all cereal prices is very similar in Burkina Faso (Figure 10), with millet being slightly more expensive than sorghum and maize. Minimum prices happen just after the harvest, and increase by half at the beginning of the rainy season ("soudure" period). Mean prices are correlated with the distance to important production centers or important markets: the prices are highest in Sahel region, which is an area that regularly suffers form cereal deficit (Figure 13), and lowest in the south-west Mouhoun region (also called the granary of Burkina Faso).

Imported rice prices (not represented) are perfectly stable and vary between 24,000 and 26,000 FCFA/100 kg bag depending on the market (Ouagadougou being the cheapest and Sahel the most expensive).

An important variation occurred around the devaluation of the CFA, in 1994 (Figure 11).

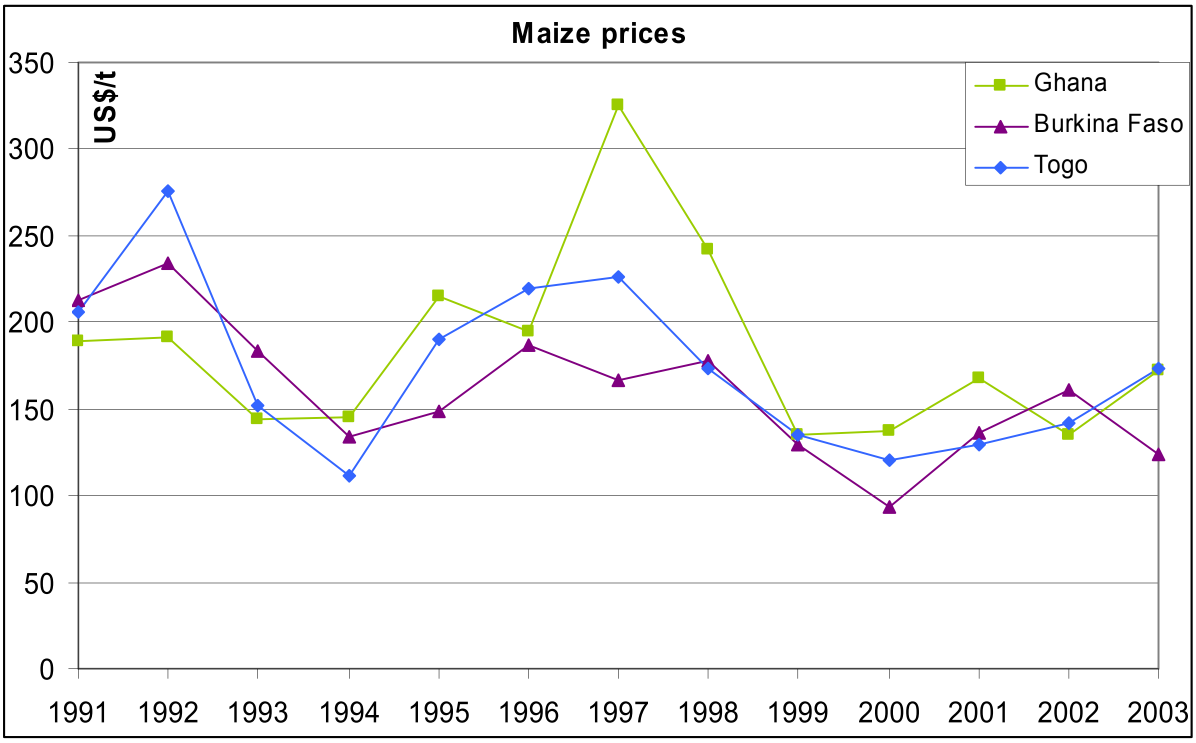


Figure 11: Maize prices variation in Ghana, Burkina Faso and Togo between 1991 and 2003. Source: FAOstat http://faostat.fao.org/site/352/DesktopDefault.aspx?PageID=352

2. Geographical distribution

a) Distribution of production/crop

Cereal production in Burkina Faso has always shown two different agricultural areas: western provinces produce surpluses, whereas the north of the country undergo regular deficit (Figure 12).
Northern provinces suffer from regular food shortages at the beginning of the rainy season: when food shortage appears in the North, producers from the West have difficulties to sell their production.

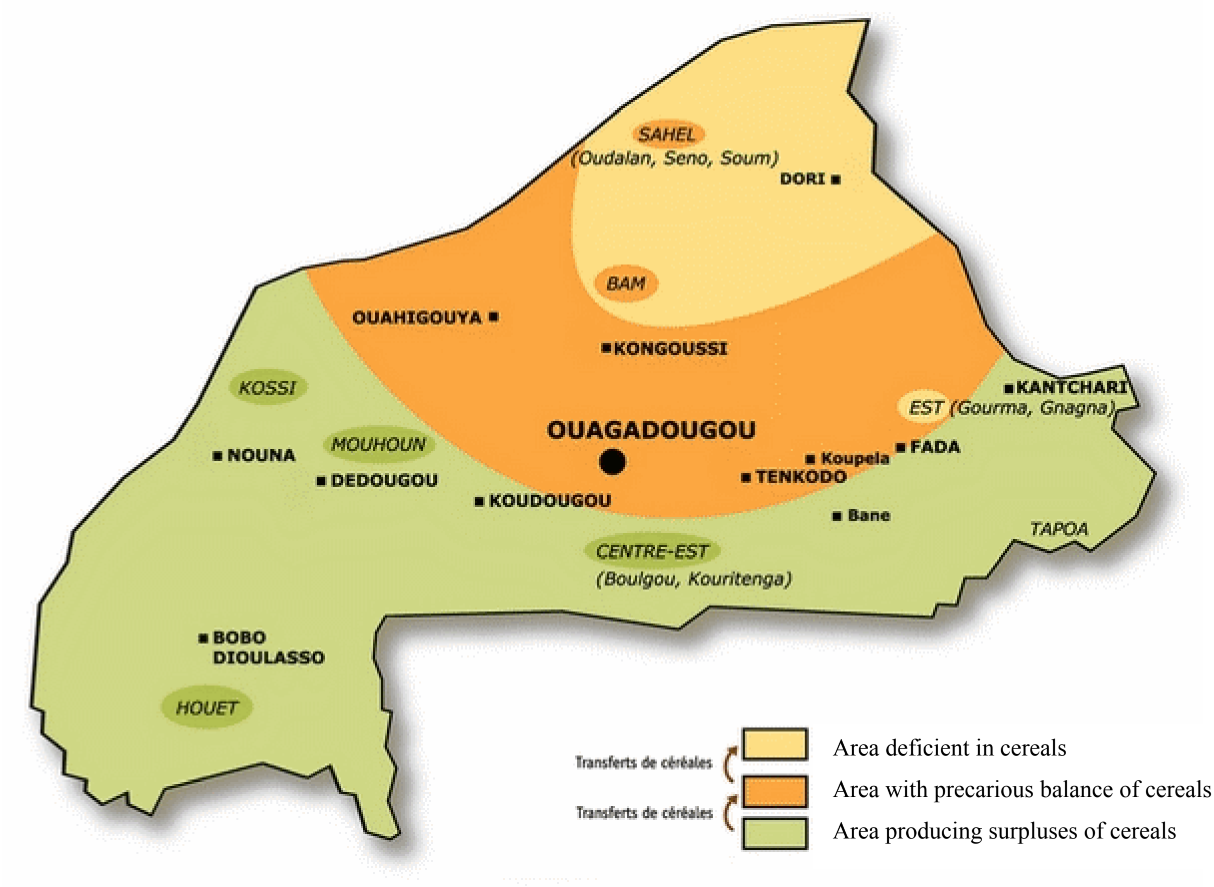


Figure 12: Food security areas in Burkina Faso (Source: Afrique verte, http://www.afriqueverte.org)

Figure 13 shows the distribution of calorific production for starchy crops in the basin. High areas of production are the West and south of Burkina Faso as well as a band around 8°N in Ghana.

But one can notice that the basin is not isolated. In Ghana particularly, big cities and high density zones are located out of the basin. The Ghanaian part of the basin, growing more starchy food than the rest of Ghana, has to feed Accra, Kumasi, and the coast. Kadiogo, the province of Ouagadougou, is very urbanized and this trend is accelerating, resulting in a decrease in agricultural lands.

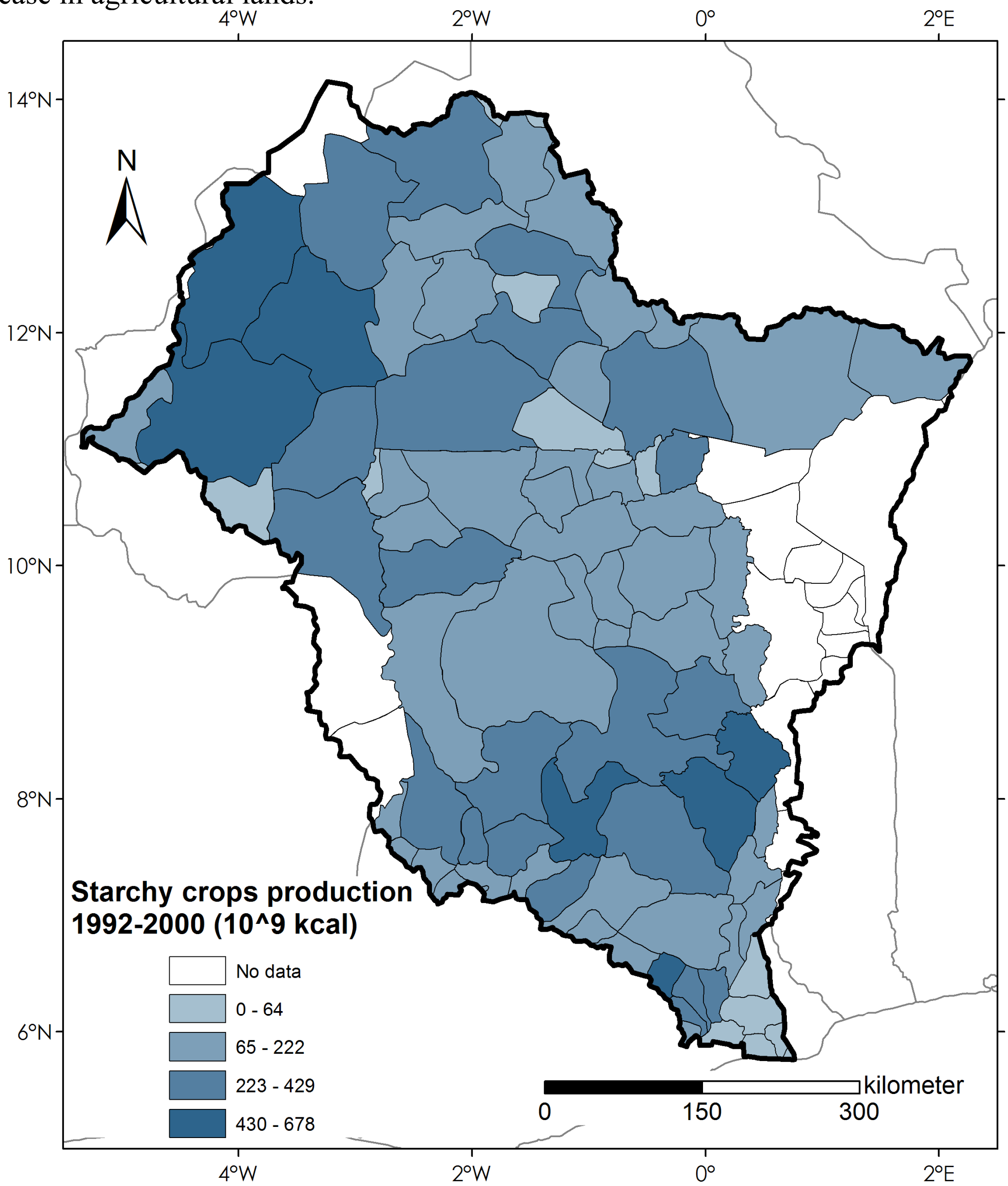


Figure 13: Mean calorific production in the Volta basin (period 1992-2000, data from MAHRH and MOFA converted into energetic content).

b) Distribution of cropped area

Maize and rice are grown in the whole basin while sorghum and millet productions are concentrated in the northern two thirds and fonio in the northern quarter (Figure 14). The south-west of Burkina Faso, called the 'granary' of the country, is an important producer of maize, like the northern part of Ghana and the south-west of the basin. Maize cropped area is decreasing in the North of the basin and in the center of Ghana, whereas it tends to increase in the south of Burkina Faso/Northern Ghana and near the south-west border of the basin in Ghana. Rice cropped area is significant only next to the eastern border between Burkina Faso and Ghana, but globally increasing, maybe due to the increase in small dams number or the increase of its popularity.

Yam is cropped in the south two thirds of the basin, and cassava in the south third (Figure 14). Cassava covers the largest percentage of district area on the border south-west, while maximum yam cultivation is observed around 8°N parallel. Cocoyam cultivation only occurs in the very south of the basin. Cassava cropped area globally seems to extend. A trend in increasing yam cropped area is also noticed, but mitigated by local declines.

Research needs to assess impacts of the global climate change on the cropping systems, and on farmers’ practices.

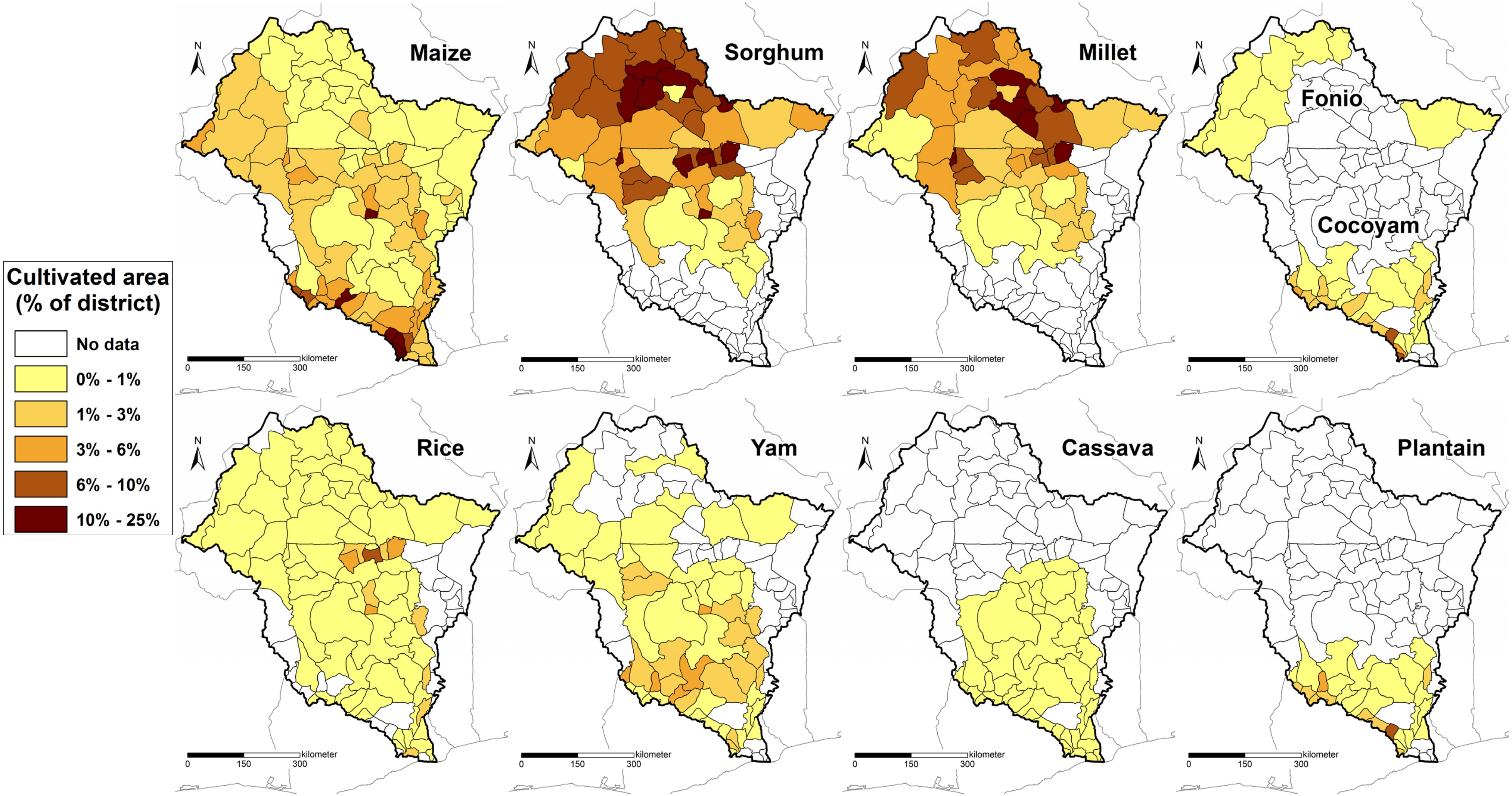


Figure 14: Mean percentage of cultivate area for each starchy crop in the Volta Basin (period 1992-2000, data from MAHRH and MOFA).

c) Distribution of yields

The mean cropped area distribution of maize (period 1992 - 2000) turned out to match approximately the distribution of maize yield (Figure 15). The south-west of Burkina Faso recorded the best yields, because fertilizers were more commonly used in this cotton producing region (Ministère de l'Agriculture de l'Hydraulique et des Ressources Halieutiques, 2006). In centre of Ghana, maize yields were quite low as the main limiting factor seems not water but the fertility of soils, and particularly low P-fertility and a N-fertility lower than in the south (Food and Agriculture Organization).
Distribution of yield and cropped area seem quite similar for yam. This observation is also true for cassava and plantain.

Sorghum and millet show different distributions: their yields were much higher in Ghana than in Burkina Faso, although these crops were mainly cultivated in the north of the basin. This paradox can be explained through comparison with other crops. In fact, yields of millet and sorghum overtook maize yields in the extreme north of the basin, but became much lower than maize yields in southern Burkina Faso and Ghana, hence Ghanaian farmers prefer other crops than millet and sorghum.
Moreover, millet and sorghum are known to be far more drought and dry spell resistant than maize, which are both quite frequent in the north. This field observation agrees with theoretical approaches based on crop modeling. The growth environment of millet, and especially its water needs, has been assessed using an Aridity Index (Badini et al., 1997). When applied to the determination of agricultural productivity in Burkina Faso, the index indicated i) that below 500 mm of annual rainfall, millet production was not promising, but was maybe the only possible cereal cropping, and ii) that productivity increased towards the central zone of the basin, together with a decrease in inter-annual variability.

Districts where important rice cropped area is observed are those where mean yields are high. Conversely, there are other districts where rice yields are high and cropped area is low. This may be due to the fact that rice is often cultivated on irrigated land or inland valleys. Its cultivation thus requires equipment, which cost limits its spreading.
For fonio and cocoyam, the scarce data make it difficult to conclude.

To summarize by climatic region, the north Sudano-Sahelian zone shows slight decline in kilocalories production and in maize cropped area, but stability for total starchy crops production, millet and sorghum, with very low yields for the three cereals.
The south Sudano-Sahelian area remains stable for cropped area and calorific production, with slight increase in Northern Ghana. The maps show increase in maize and sorghum cropped area, with a slight decrease in millet. Yam tends to extend in the multi-cereal area, and to regress in the cotton area.
In the Sudanian area, it is difficult to highlight trends, as the behavior of each district seems particular.
The Guinean area looks dynamic, except the area next to Ivory Coast: cropped area and calorific production tend to increase, such as maize, yam and cassava although their yields are already quite high in this area.

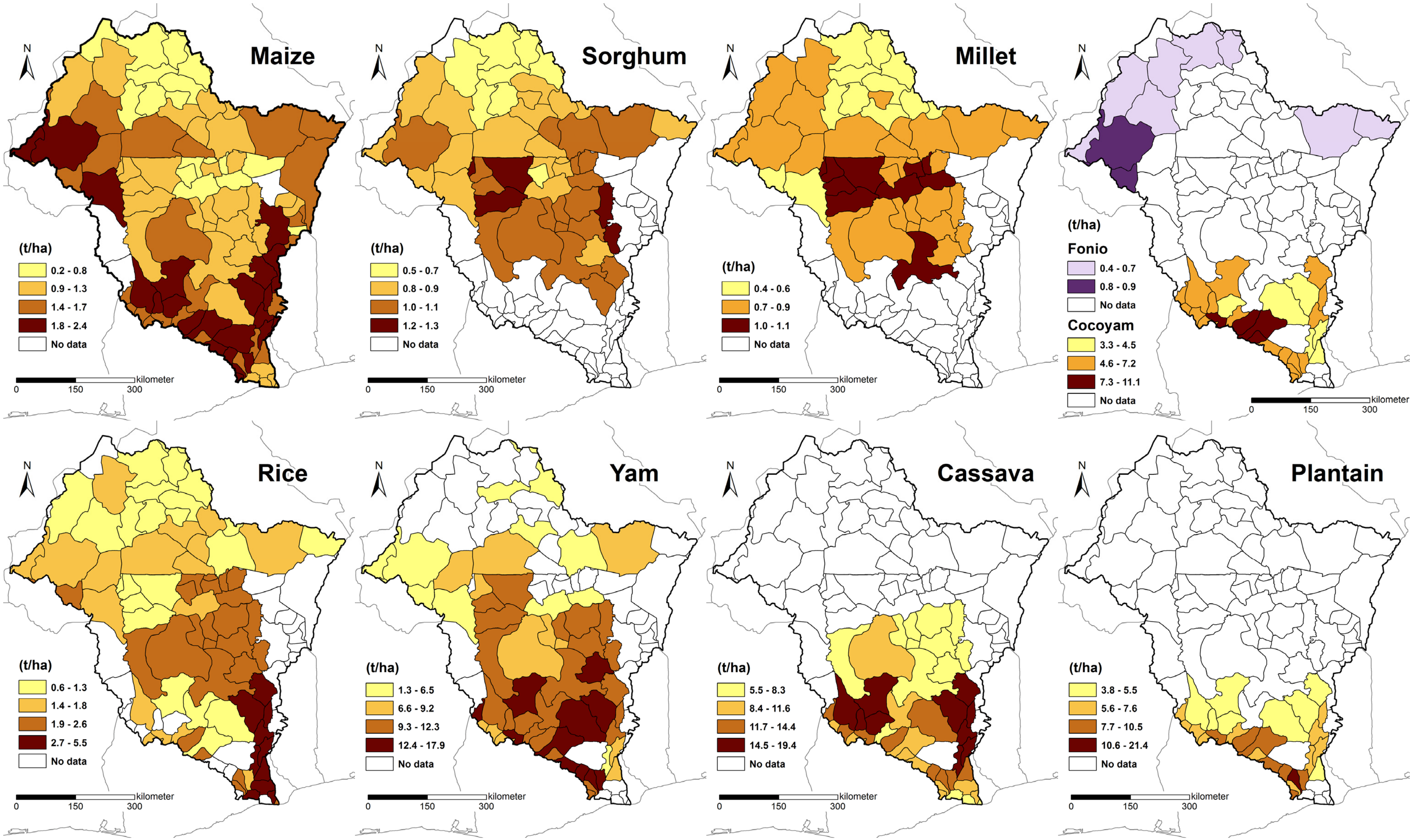


Figure 15: Mean yields for starchy crops in the Volta basin (period 1992-2000, data from MAHRH and MOFA).

3. Organization of the sector

a) Burkina Faso

Despite abundant production of cereals (Burkina Faso is auto-sufficient for all cereals except rice), the supply of some locations (particularly in the North) can be very bad. People may suffer food shortage even when other regions produce surpluses.
Cereals cropped area covers about 4 millions hectares, which largely overhauls commercial crops 800,000 ha (2002, 2003). Markets are regionalized: cereals sold in BF are a mix of cereals from Mali, Niger, Côte d'Ivoire or Ghana. But prices differ according to the regions. Information about cereals prices does not reach farmers that sometimes consider the amount of rainfall as an indicator.

The absence of synergy between state representatives, producers, transporters and retailers makes difficult the sufficient availability of cereals over the whole territory. Hope raised by the "Société de promotion des filières agricoles" (SOPROFA) faded away and the "Société nationale de gestion des stocks de sécurité" (SONAGESS) acts only in extreme cases. Speculators abuse farmers, by getting them into debts before harvest and buying their production at very low prices.

There are no agricultural investment credits for cereals producers, except for the cotton zone (Ducommun et al., 2005).

According to the « Comité interprofessionnel des céréales du Burkina Faso » (CIC-B), the cereal production sector is much unorganized. A *Plan d'action sur les céréales* (millet, maize, sorghum) has been produced in 1998, updated first in 2002 and later in 2003 to add cowpea and create the CIC-B. The inputs used are remaining from cotton, but are not adapted to cereals.

More investigations would be needed to see if there are regions where staple food production is decreasing, if there is an evolution in the cropping and what could be possible reasons behind it (prices, climates…).

b) Ghana

Ghana's agricultural economy is very vulnerable as about 90% of agricultural output goes directly in the raw form to final sales and consumption. This is at the expense of agro-industrial processing opportunities which offer the greatest prospects for rapid economic growth and prosperity. The absence of an effective agro-industrial processing capability therefore constitutes one of the major missing links in Ghana's quest for sustained agricultural growth and development (Dapaah, 1999).
To date, the likelihood of having Ghanaian agriculture transformed is greatly limited by unfavorable macro-economic policies that actively discriminate against investments in the agricultural sector and consider agriculture merely as farming (Dapaah, 1999)..

4. Potential of evolution – foodcrops become cashcrops?

The growth of urban purchasing power may foster agricultural development provided farmers and herders are able to satisfy the demand (Ducommun et al., 2005). Urban purchasing power would create agricultural income, which may become rural purchasing power to buy urban goods (virtuous circle).

In Burkina Faso over a third of produced foodcrops is sold on the market, becoming de facto cashcrops. Making a national extrapolation, the annual selling of foodcrops reaches a minimum of 180 to 220 billion FCFA, which is the triple of the cotton sales.
Given their potential of manpower, 60 to 80% of the foodcrops production units could strongly increase their production if they could access investment credits to purchase equipment and animal traction (Ducommun et al., 2005).

Land is not yet saturated: in Burkina Faso, only half the arable land of the country is effectively cultivated; in Ghana, this figure reaches two thirds.

To satisfy an increasing demand, the development of rainfed agriculture will necessarily have to be complemented with a diversification of practices such as irrigation in dry season cultivation.

C. Cashcrops: the cotton example

Burkina Faso is the 1st producer of cotton in Africa (White gold). Cotton producers gather locally in "Groupements de producteurs de cotton" (GPC). These are further organized in "Union Départementales", then "Union Provinciales" who in turn organize the assembly of national unions. The *National Union of Cotton Producers* (UNPC-B) and the Association for *Cotton Societies* (APROCOP) form the interprofessional association in Burkina Faso. Cotton producers are shareholders of SOFITEX by 30%, of Fasocoton by 10% and of SOCOMA by 20%. These 3 main companies of commercialization are gathered into APROCOP.

A price smoothing process is implemented every year (April, 1st) by the "Association Interprofessionnelle du Coton du Burkina" (AICB: 8 members from APROCOP and 8 from "Union Nationale des Producteurs de Cotton" which fixes the bottom price for cotton seed. In 2007, the price was 145 CFA/kg for 1st choice and 145 CFA/kg for 2nd choice (it was 165 CFA/kg in 2006). It is conjugated to a rise in inputs: fertilizer and urea prices are respectively 15,485 and 16,720 CFA/ha although they used to cost 12,400 CFA/ha in 2006, while insecticide rose from 4,040 to 4,362 CFA/ha. Finally, the total production cost rose from 73,840 CFA/ha to 89,347 CFA/ha, halving benefits from inputs (http://www.lefaso.net/spip.php?article20892).

Cotton plays a very important role in Burkina Faso economy, with 320,000 families (about 4 million people) living directly from revenues from this sector. The state supports the sector with subsidies on inputs.

Cotton farmers are strongly affected by world market prices for cotton. World cotton prices are currently at their lowest levels for thirty years, at half the long-term average. This is the result of a large global harvest, partly a consequence of high subsidies paid to farmers in developed countries, combined with low levels of demand (Toulmin and Gueye, 2003).

III.CROPS RESPONSE TO WATER CONSTRAINTS

At the basin scale, the comparison between farming systems and rainfall distribution reveals a clear and crucial impact of rainfall patterns in agronomy. However, it is quite difficult to capture variables describing the characteristics of rainfall that are crucial for agriculture.

A simple model of soil water balance can highlight the dispersion of crop response to sole annual rainfall. Soil infiltration is extremely variable and depends much more on succession of rain events than on the annual amount. To illustrate this, Figure 16 shows simulated annual soil infiltrations for several time series of daily rainfall observed in a Sahelian sedimentary region. For a given amount of annual rainfall, e.g., 500 mm, there is a large range of possible values for annual infiltration, e.g., 0 to 150 mm.

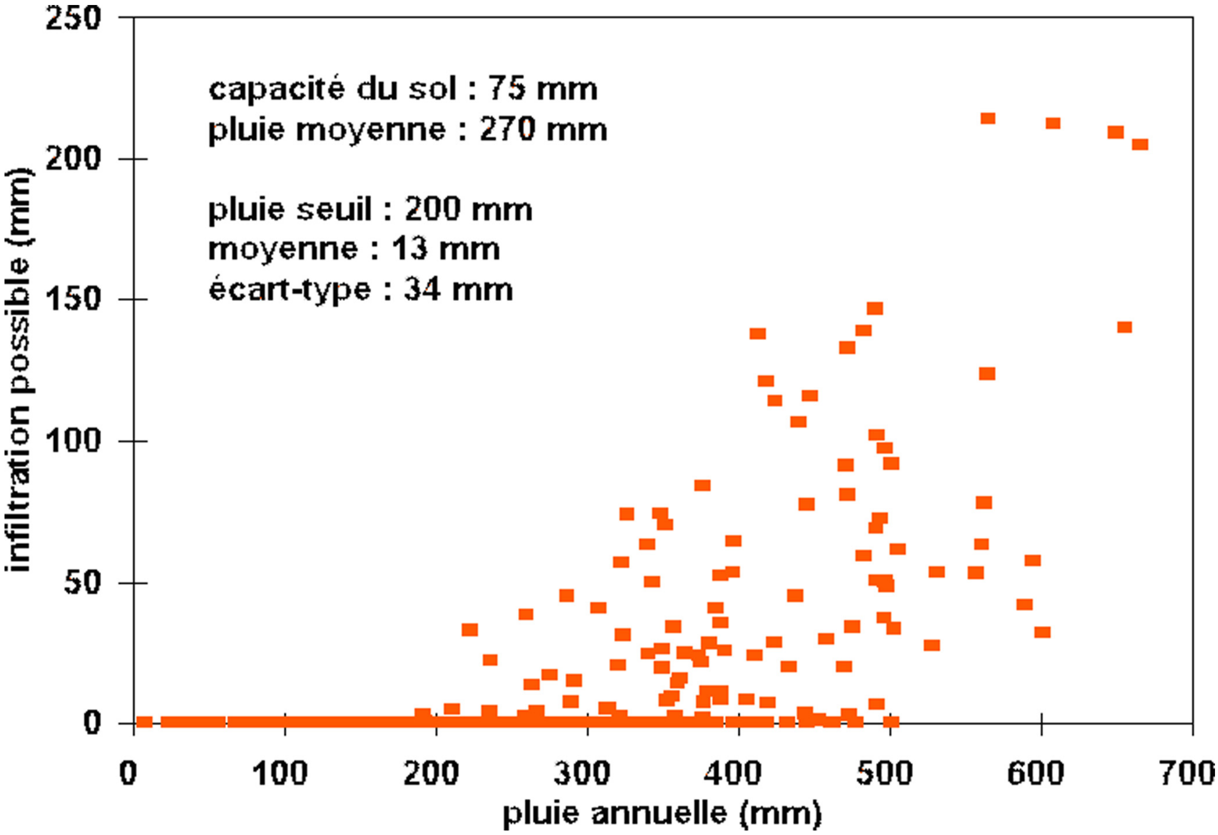


Figure 16: Simulated annual soil infiltrations for several time series of daily rainfall observed in a Sahelian sedimentary region (source: Leduc (2003)).

In addition the crops undergo many more constraints: soils diversity, different agricultural practices, range of cultivated varieties for a same crop and also biologic hazards (insects…) which induce a very high variability of the vegetal production response to annual rainfall.

A. Yields

In Figure 17, yields are plotted as a function of rainfall for the period 1992-2001 for Ghana and 1984-2001 for Burkina Faso to get a wider range of rainfall (which was particularly low in the 80's). The yields have been collected from the Ghanean and Burkinabe ministries of agriculture and they correspond to mean annual yields for administrative units (district in Ghana, province in Burkina Faso). The data and sources are described in paragraph II.A. These figures have been matched with the corresponding annual mean rainfall computed for the same administrative units on the basis of the global grid monthly precipitations from the Climate research Unit (CRU) 0.50° (CRU TS 2.1) (Mitchell and Jones, 2005).

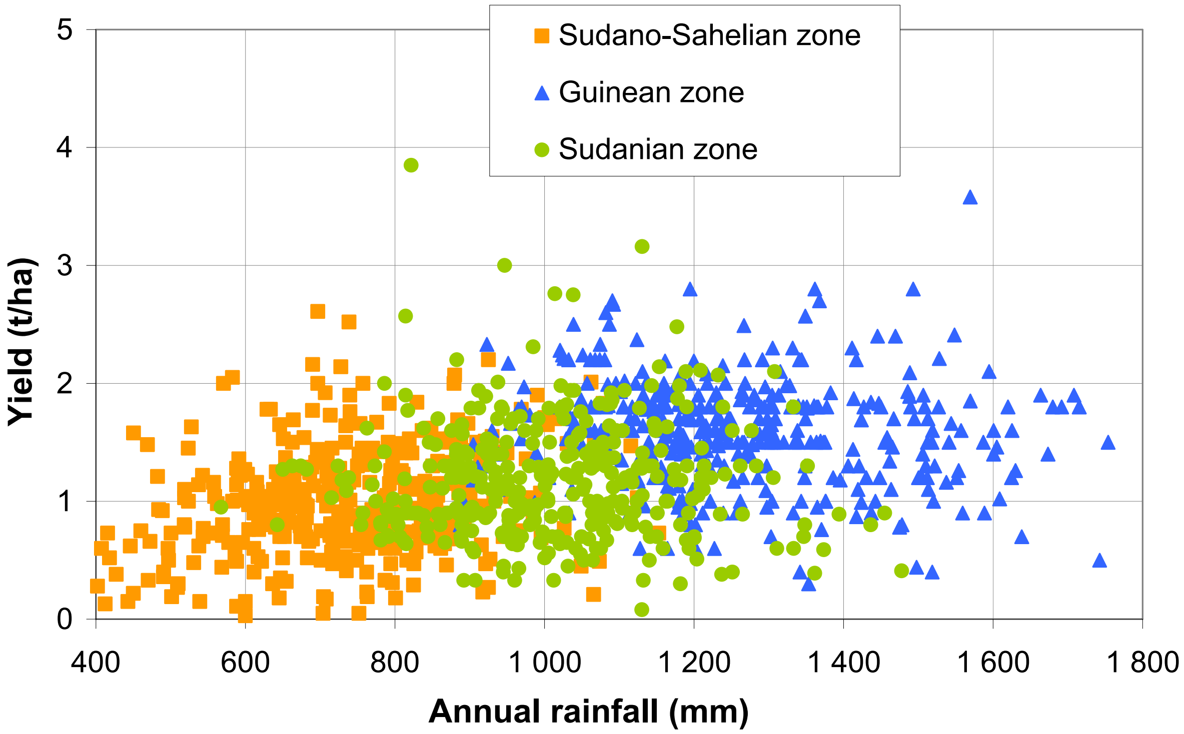


Figure 17: Maize yields in the Volta basin as a function of annual rainfall (period 1984-2001 for Burkina Faso and 1992-2001 for Ghana; data from MAHRH and MOFA).

The dispersion of the clusters of points is very important. There is a poor tendency of yield increase from the Sudano-Sahelian to the Sudanian climatic zone, while no particular tendency appears in the Guinean zone (Figure 17). Annual rainfall influences more yields in the Sudano-Sahelian zone than in other climatic zones.

B. Water productivity

When water is scarce, or when there is competition for water use, it may be useful to analyze how much production can be achieved for a given volume of water. This is particularly useful for irrigated crops (Rockstrom et al., 2003). A number of definitions of water productivity (WP) were defined, some of which focus on the use of water by the plant (Bouman, in prep). Here, we focus on the rain water needed at field level to satisfy crops produced mainly in semi-arid rainfed situations. It is assumed that a crop can grow only if sufficient rain is received by the field, no matter what happens to the water (evapotranspiration, runoff, seepage etc.).

This leads to a simple definition of WP for rainfed agriculture as the ratio of harvestable yield to gross inflow (Cook et al., working paper), that we can compute by dividing the grain yield (kg/ha) by the amount of rain received by the field (m3/ha).

$$WP = \frac{\text{Benefit}}{\text{Cost (Water)}} = \frac{\text{Production}}{\text{Water applied}} = \frac{\text{Yield}}{\text{Rainfall}}$$

Figure 18 shows water productivity as a function of rainfall for maize. Values are very low, with a mean of 0.15 kg/m³ (σ =0.05). As noticed previously, farmers don't aim at optimizing water use but their time and labor. There is a poor tendency of WP decrease from the Sudanian to the Guinean climatic zone, while no particular tendency appears in the Sudano-Sahelian zone

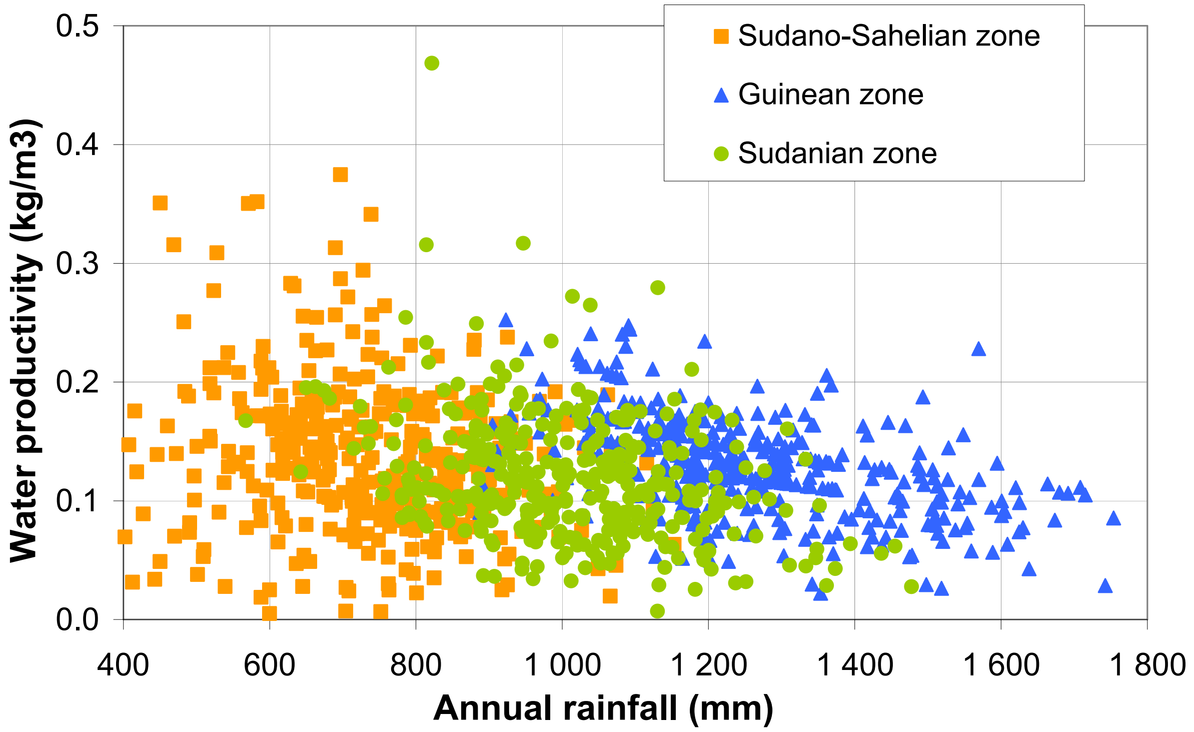


Figure 18: Maize water productivity in the Volta basin as a function of annual rainfall (period 1984-2001 for Burkina Faso and 1992-2001 for Ghana; data from MAHRH and MOFA).

Distribution of water productivity

For a mean rainfall location, such as the central part of the basin, the distribution of water productivity is relatively similar to that of yield (Figure 19 vs. Figure 15). In the driest part, where water availability is the main limiting factor, WP values were proportionally higher than for yield (as the denominator for computing WP was smaller than in the rest of the basin). In the southern half of the basin, maize yield benefits from an increase in rainfall and its WP distribution follows yield, whereas water productivity for millet and sorghum dropped.

Rainfed WP has to be interpreted according to water availability, i.e., whether the area has a rainfall deficit or excess compared to crop needs. Consequently, for rainfed agriculture, water productivity distribution does not seem to add much more information than yield distribution.

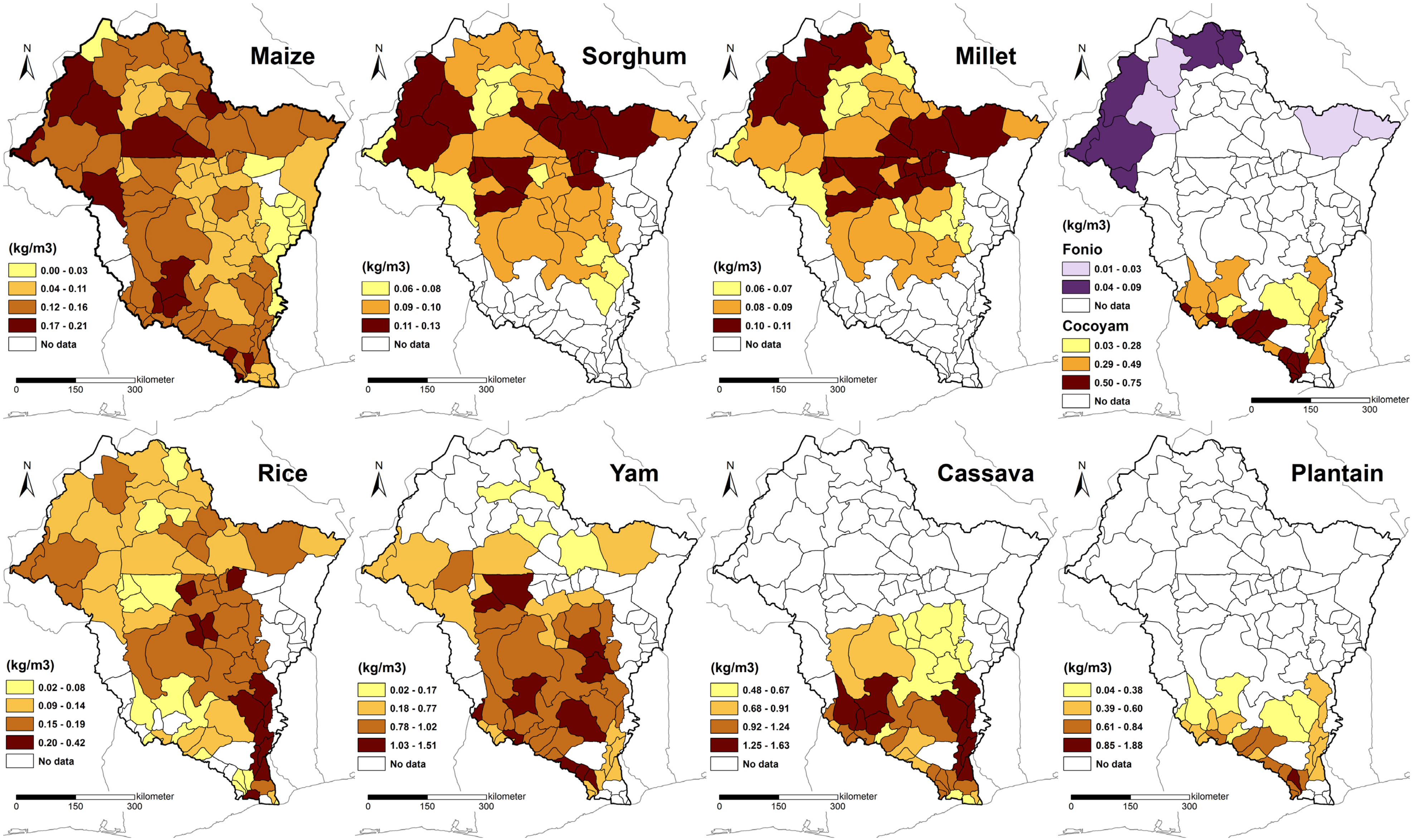


Figure 19: Mean water productivity for starchy crops in the Volta basin (period 1992-2000, data from MAHRH and MOFA).

C. Discussion

The limited relationships found between rainfall on the one hand and yields/water productivity on the other hand may still be explained by the spatial and temporal variability of rainfall. The rainfall variable taken into account was annual rainfall without consideration of its temporal distribution within the year. For instance, rain falling out of the growing season has no influence on yields and dry spells happening in critical crop development stages (such as flowering or grain filling for maize) can have dramatic effects on yields, independently to the annual rainfall amount. A simulation with SARRA-H, applied to the square degree of Niamey in Niger, showed that , low annual rainfalls between 200 and 600 mm explained 63% of the millet yield variability (Balme-Debionne, 2004). Figure 17 showed that the driest the climate, the more important this tendency.

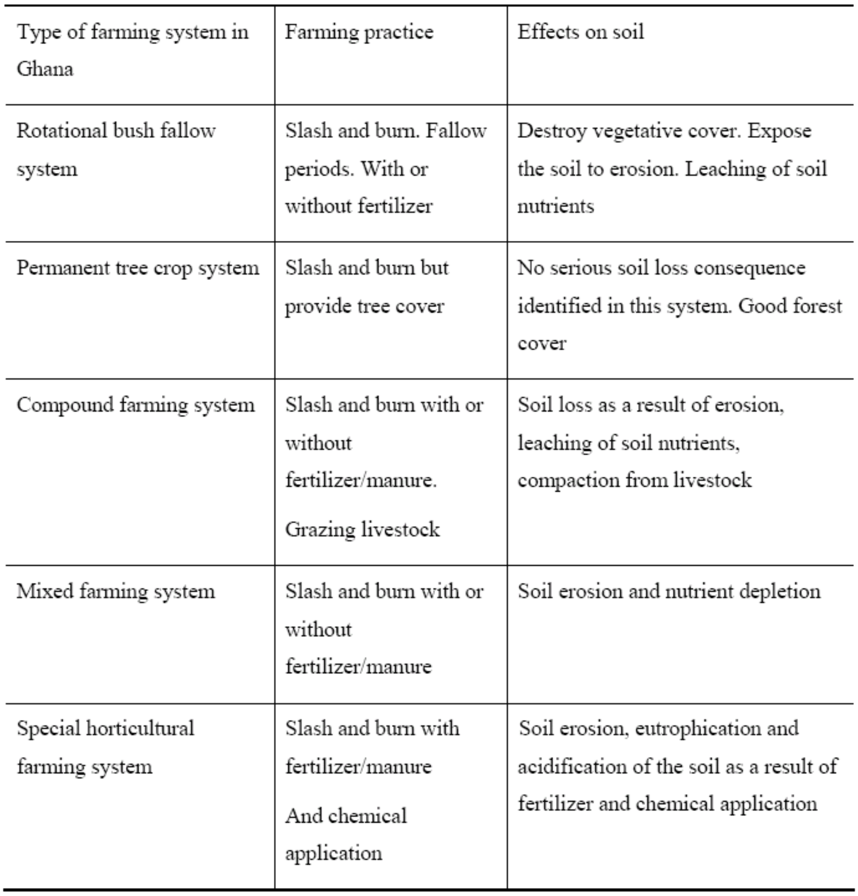
Furthermore, the rainfall considered here is a smoothed spatialized variable obtained by interpolation of rainfall gauges measurements while the spatial variation of annual rainfall in this region of the basin may be tremendous. If we consider the one square degree near Niamey (Niger, Sahelian climate) for instance, , the rainfall ratio between maximum and minimum annual rainfall records is approximately 2, whereas the regional rainfall gradient would lead to a ratio of 1.2 (Balme-Debionne, 2004). In another study, total rainfall gradients of 42 and 64 mm km^{-1} have been observed around 13°N in 1995 and 1996 respectively within a 500 ha grid at the ICRISAT Sahelian Center in Niger(Graef and Haigis, 2001). At a shorter time scale, and on the same spatial grid, analysis of rainfall events indicated that spatial variability over short distances (field to village) is more significant than on the regional survey level scale. The subsequent yield variation may be important too, but we only have district spatial means. Besides, official agricultural data are an extrapolation to the district of a limited number of field estimates and errors may be important.

Distribution of the different cereals in the basin results from their profitability and from risk avoidance by farmers. The temporal and spatial variability of rainfall within short distances in semi-arid regions is well known by small farmers in the basin. They prefer to cultivate different fields that are some distance apart one from another, to diversify the varieties grown, to space out sowing date (Eldin and Milleville, 1989). They adapt therefore to climatic risk by decreasing the production variability and especially minimizing crop losses in bad years.
Furthermore, two successive agricultural years are related: a good or bad year will have consequences on the agricultural choices the following year.

As a result of rainfall spatial variability and risk avoidance strategies, observed yields for an administrative unit are in fact an aggregation of various field yields (corresponding to numerous varieties of a given crop), resulting from diverse rainfalls which are themselves lumped in a single value. Consequently, the water productivity at district scale is entailed by some uncertainty.

IV. SUSTAINABILITY OF FARMING PRACTICES

Each cropping system induces side-effects on the environment. Table 5 recapitulates the effects of the different cropping systems in Ghana.



Type of farming system in Ghana	Farming practice	Effects on soil
Rotational bush fallow system	Slash and burn. Fallow periods. With or without fertilizer	Destroy vegetative cover. Expose the soil to erosion. Leaching of soil nutrients
Permanent tree crop system	Slash and burn but provide tree cover	No serious soil loss consequence identified in this system. Good forest cover
Compound farming system	Slash and burn with or without fertilizer/manure. Grazing livestock	Soil loss as a result of erosion, leaching of soil nutrients, compaction from livestock
Mixed farming system	Slash and burn with or without fertilizer/manure	Soil erosion and nutrient depletion
Special horticultural farming system	Slash and burn with fertilizer/manure And chemical application	Soil erosion, eutrophication and acidification of the soil as a result of fertilizer and chemical application

Table 5: On-site effects of agricultural practices on agricultural soil in Ghana. Source: Diao and Sarpong (2007)

Nevertheless, each practice can be found in several systems, and its own impact can be isolated, as detailed hereunder.

a) Fallow practice

Fallow is a very common practice that leaves the land unseeded when yields have become low (either fertility decrease, or weeds or parasites invade). In arid or semi-arid areas this return to a “balanced savannah”, often disturbed by fires and grazing, may require 30 to 40 years. In forest areas, 10-20 years may be enough. Nowadays fallow periods are much shorter, often less than 5 years, and cultivated periods are much longer.

Fallow practice restores organic and nutrients stocks, which may be used in the next cultivated period. The soil’s fauna disturbed during the culture regenerate as well during fallow period.

Research is required to study the impact of (i) a reduction in the fallow periods duration, and (ii) the over exploitation during the fallow period of animal and vegetables species that are necessary for maintaining or regenerating soil physical and chemical properties (Serpantié 1993).

b) Role of cattle in agriculture

Livestock brings three main contributions to the evolution of agriculture. First, animal manure replenishes the soil fertility by restoring partly the nutrients removed by cultivation, thus contributing to sustainability of agriculture. Second, animal traction is important either in increasing the productivity of smallholders by providing power for land preparation (intensification scenarios), or in enabling cropping area extension (extensification scenarios). Third, livestock is a source of cash income enabling farmers to purchase inputs, food and other needs (Christiaensen et al., 1995; Hauchart, 2007).

The extension of mechanized practices stimulates cattle acquisition complementary to farming.

After harvest, cattle pasture crop residues, which facilitates organic matter decomposition and improves its bioavailability (Bosma and Bicaba, 1997). Their faeces and urine enrich land with potassium and nitrogen. The consequent increase of agricultural production is significant as cereal yields double (Sangaré et al., 2001).
However, the necessary fertilization (2 t/ha/year) requires 4 cattle per hectare during the whole dry season, which is often beyond available livestock. In addition, forage resource (natural pasture and crop residue) is insufficient to reach this rate (Serpantié, 2003), especially during the dry season. Animal husbandry development tends to provoke overgrazing which prevents re-vegetation in Sahelian zones. Finally, PRIPODE project proved that the absence of land tenure security leads migrants to use natural resources unsustainably (CICRED, 2006 and 2007).

Research would be needed on the role of overgrazing in soil degradation and resources depletion, in comparison to climatic constraints and cultivation.

c) Consequences of traditional and manual techniques

(1) Land clearing

During the land clearing step, manual weeding preserves some stubs and useful trees which avoid soil disturbance. The residues are burnt, which destroys 80 to 90 % of vegetal matter: nitrogen is depleted into the atmosphere and ashes spread out. In addition, flames modify the soil surface condition and reduce it porosity, which increase runoff and erosion (Serpantié, 2003). The severity of the impact depends on the period: late burning leaving bare soil just before heavy rains increase runoff from 1 to 15 % and soil loss from 40 to 400 kg/ha/year (Roose, 1985), even with low slopes < 1 %.
Burning can be positive if weed bunches are burnt, spread and ploughed in, as ashes help reducing acidification.

(2) Seeding

Direct seeding does not disturb meso-fauna activities and protects soil from splash erosion. Dry scarification increases infiltration and reduces erosion (Some, 1989). Theses practices hardly allow to burry organic matter and produce lower yields.

(3) Intercropping

Traditional intercropping is very positive. It allows:

- time saving during cultural operations and thus a better management of the working force (Kaboré and Reij, 2004),
- a better soil cover, in particular in case of sorghum and procumbent plant (such as cowpea), that protects soils from splash erosion. Impact of raindrops on soil surface decreases by 36 % (Mietton, 1986). It also maintains soil wetness, which enables cereals to resist better to dry spells and decreases risk of crop failure.
- spacing out seeding, which optimizes water resources use (Da, 2004).
- better fertilization, when pulses are introduced within the associations, as they fix the atmosphere nitrogen.

(4) Agroforestry

Tree roots structure soil, and bring up nutritive elements that had been drained too deep. Decomposition of tree leaves fertilizes top soil layers (Veihe, 2000). The reduction of erosion and thickening of litter enhances organic matter availability (+50 % under shea trees and locust beans according to Serpantié (2003)). Soil wetness retention increases while evapotranspiration decreases (in particular shea tree leaves contains a waxy matter that slows their decomposition). They also create ecological niches that favor biodiversity regeneration (Adropogon gaianus).

Trees compete with crops for water and nutrients resources, especially when these resources are scarce, except for deciduous species (e.g., *Acacia albida*).

(5) Rotations

Crop rotation limits parasite and vermin attacks and, on the other hand, slows down the decrease in organic and mineral soil fertility. This is all the more crucial as fallow tends to disappear or to be shortened, and is not compensated by fertilizers or manure applications (Some, 1989). As a consequence, physico-chemical properties of soils tend to degrade and soil structure becomes unstable, favoring erosion and runoff.

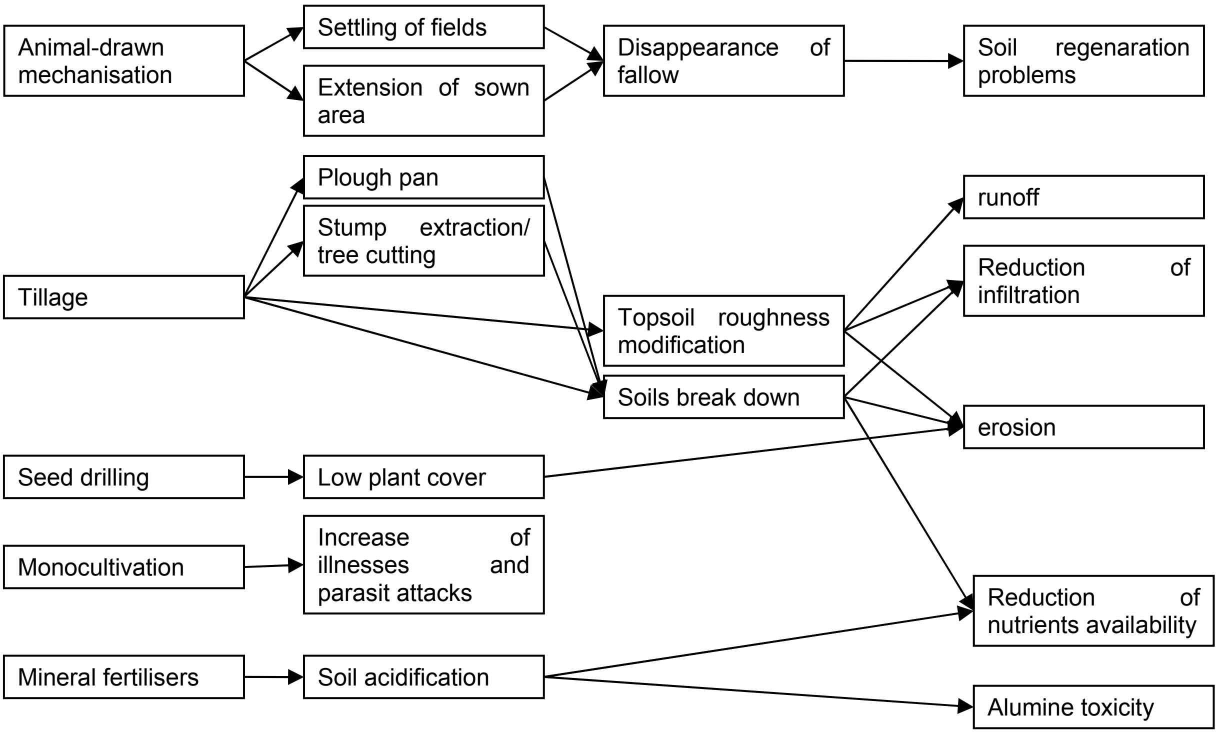
To conclude, manual and traditional cropping practices have positive or neutral consequences on the environment, but their productivity is too low, and too irregular to ensure a sufficient agricultural production. Some techniques such as the intercropping cereals-pulses are more adapted to both productivity requirements and environmental protection.

Traditional practices impacts on runoff, erosion and productivity ("semis en foule", "semis en sec", "semis direct", "grattage superficiel du sol à la daba", "sarclage manuel avec abandon sur place des adventices") should be investigated more in depth so as to determine their potential for integration in a sustainable and productive agricultural system.

d) Impact of modern techniques (intensification and extensification)

Tillage, monoculture, ridging, mineral fertilizers and phytosanitary use, have direct consequences on the environment while suppression of fallow land and extension of cropped area effects are indirect. Mechanization implies a larger cultivation period and often application of mineral fertilizers to make the investments beneficial (time, energy, material).

In areas where modernization is widespread, intensive cultivation does not cover the whole cropped area one given year, but as it enters crop rotations, its impacts gradually extend to the whole cropped area. The following scheme summarizes the negative impact chains of intensification practices.



(1) Land clearing

Intensification has induced a shift from the natural vegetation to fallow vegetation, with a predominance of annual and semi-perennial plants, for instance grassy weeds in permanently cultivated fields. Farmers' efforts consequently shifted from land clearing after fallow to control of increasingly predominant and aggressive weeds (Weber et al., 1996).

In mechanized farms, land clearing is more intense than in traditional cultivation: it includes stump extraction and tree cutting which disturbs soil structure. The consequent soil disturbance is all the more important as the following culture is intense and inappropriate for the environment, which may even lead to barren and unproductive soils formation. Stump extraction leaves holes that are seldom filled and deprive soil from the fertility of stump putrefaction (Hauchart, 2007).

(2) Tillage

Depending on the conditions of tillage, its effects may be very varied. It increases the roughness of topsoil and, as a consequence, soil aeration and water infiltration. It also improves the rooting of crops and increases the plants density, which increase yields (Barro et al., 2005). Its effects will be improved if it is used at the same time to plough manure (Ouattara, 1998) and in case of coarse tillage coupled with manual clod breaking. However, positive effects are not sustainable: tillage tends to increase erosion of colloids and reduce consequently active storage.

On the other hand, tillage is inadequate to local conditions and breaks soil down on a depth of 20 to 25 cm. In this mixed layer, erosion is accelerated for slopes > 0.5%, and may sterilize soil after only 2 or 3 years of cultivation (Charrière, 1984). Besides, tillage breaks deep soil structure and buries organic matter where anaerobic conditions are unfavorable for its decomposition. Practically, tillage is often superficial and crushes topsoil into powder which is easily eroded. Maximum erosion exists until seedling offer sufficient protection. It induces elutriation (selective erosion) with fines flowing towards holes and bottoms. Consequences are particularly negative on light soils, which are easily de-structured, and leached out.

Tillage also entails the creation of a hard pan below a depth of around 70 cm, where soil is compacted, inhibiting infiltration and roots penetration.

With animal-drawn tillage, the location of cultivated fields tends to settle and touring cultures have been regressing. Thus, fallow tends to disappear, which induces a decrease in porosity (-15% in 10 years), a loss in organic and mineral nutrients and a decrease in structural stability (Boli et al., 1993; Hien, 1990). After 15 years of animal-drawn tillage cultivation, nutrients losses approximate 50 to 60% (which is equivalent to 80 years of manual cultivation).

In extensification systems, sown area has been extended thanks to mechanization: farmers cultivate fields farther from villages (Hauchart, 2007). The need for new fields induces deforestation (PRIPODE). In the 2 study areas located in the Sudano-Sahelian zone, spatial distribution of vegetation degradation has been observed, which increased soil erosion (gullying, stripping and sapping of banks) (CICRED, 2006 and 2007).

(3) Seeding

Monoculture has been adopted to meet the specific requirements of phytosanitary treatments but it favors spreading of illnesses or parasites attacks (Silvie et al., 1993). On the other hand, plant breeding has done much to develop host plants resistance to pests attack, thus stabilizing yields (Weber et al., 1996). Seed drilling does not provide an optimal plant cover, which exposes soil to erosion and runoff, all the more as plant development is slow. Ridging of furrows can be positive if furrows are perpendicular to the slope (it reduces runoff) or if it is complemented by hoeing that break superficial crust.

(4) Fertilization

Fertilization is often mineral, which helps in increasing productivity and stabilizing yields, but which medium and long term effects are negative. Modernization allows increasing productivity, which improves food security and release a commercial surplus. But as intensive techniques are badly monitored, increase in productivity does not always make investments beneficial (Hauchart, 2007). The decline in soil organic matter is closely associated with land use intensification. It is a problem common to fertile and moderately fertile uplands under market-driven intensification and moderately-fertile and degraded uplands under population-driven intensification.

However, fertilization calendars are seldom respected for economic, cultural, or technical reasons, which tempers the positive effects of this practice on productivity. The basic fertilizer

is commercialized mainly by cotton companies and is reserved to cotton producers, all the more as its cost requires to be creditworthy or to possess cash.
But mineral fertilization (in particular Nitrogen) induces soil acidification that reduces nutritive resources availability (Ca, Mg) and organic carbon rates (Bado et al, 1997), prevents a good assimilation of P and K, and provokes alumina toxicity. These effects can be reduced by an association with organic fertilizers.

There is a need for creating agronomic centers that analyze actual farming practices as they are implemented (not as they should be) and their impact on the environment.

(5) Socio-economic change

Self-sufficiency and land tenure of households, social organization of farming, bargaining power between crop farmers versus pastoralists and the gender equity may shift considerably with intensification (Weber et al., 1996).
Land tenure systems change from communal land ownership towards heritable rights to specific plots (Migot-Adholla et al., 1991). This change is faster in market-driven areas because rates of investment in land are greater. This impacts traditional organization of farming: traditional systems of communal land management decline more rapidly in market-driven systems as the capacity for independent farming is achieved by each individual at an earlier stage (Weber et al., 1996).

Gender equity may also be influenced by intensification. The expansion of men's cash crops, such as maize or cotton, along the pathway of market-driven intensification is accompanied by a decline in legume crops, such as groundnut and cowpea, which women normally process for sales. Additionally, in such systems women increasingly contribute to maize processing and cotton harvest, although cash from sales is entirely under men's control (Weber et al., 1996).

However, distinguishing gender crops is clearly difficult. A few crops may be considered as men's crops, such as rice, sorghum, tobacco or coffee, but relatively few farmers grow the latter two. There are gendered patterns of cropping but nevertheless no clear gender dichotomy. Female-headed households in Ghana mostly grow cocoyam, plantain, onions and eggplant. But these should not be considered as ‘‘women's crops’’ since only 30% of the total households growing these crops (cocoyam, plantain, onions and eggplant) are female-headed. However, male-headed households grow mostly the other staples, i.e., maize, yams, rice and sorghum. The latter two might be considered as "men's crops’’ since few female-headed households grow them (Doss, 2002).

Although men are more heavily involved in cash crop production, women are involved in the production and sales of all of the major crops in Ghana. The gender based cropping patterns in Ghana means that agricultural policy is not gender neutral. Many crops are disproportionately grown by men or women, depending on the ecological zone and the method of defining the farmer. Female-headed households are more likely to be directly affected by policies towards staple crops than are women farming their own land in male-headed households. The women farmers in any zone, regardless of definition, are not representative of women in general in the zone. Thus targeting women farmers only targets a subset of women. As crops become more profitable, men tend to favor selling crops to the detriment of of food crops. Further exploration of the issue of which women grow crops for the market would make it possible to target policies that increase the possibilities for women to grow more crops for the market (Doss, 2002).

Intensification induces changes between farmers and herders: crop residue becomes increasingly valuable as the land available for free grazing becomes scarce, while manure becomes increasingly important for field fertilization. However, in population-driven systems, some pastoralists tend to settle and provide dairy products, manure surpluses and meat, while livestock possession among crop farmers remains limited to poultry. However, in market-driven systems, farmers' draught animals have priority on herders' animals, which declines the bargaining power of pastoralists (Weber et al., 1996).

There is need for further research in the way newly developed technologies (crop, livestock, resource management…) may aggravate inequalities within the society in income and bargaining power (Weber et al., 1996).

e) *Influence of SWC techniques*

(1) Context

In the Central Plateau (Burkina Faso), the years of recurrent drought in the 70's and 80's provoked structural food shortages and hunger, shortages of drinking water and vegetation degradation. Yields dropped almost by half: a study by the International Crops Research Institute for the Semi-Arid Tropics carried out between 1981 and 1985 (a period of low rainfall) indicated that yields of sorghum (*Sorghum bicolor*) and millet (*Panicum sp.*) averaged 293 and 232 kg/ha respectively, whereas they usually range between 400 and 600 kg/ha (Reij et al., 2005).
It resulted in important migrations to more humid parts of Burkina Faso or neighboring countries. To address this problem, soil and water conservation methods (SWC) were developed.

More generally, when farmers notice important decrease in yields, they implement soil and water conservation techniques adapted to their climatic zone.

In 2006, most of the SWC equipments in Burkina Faso (64%) were on individual fields, only 36% were on collective fields. About 20% of home gardens were equipped, but only 12% of bush fields. This proportion ranges from more than 20% of the fields in *Nord*, *Centre-Sud*, *Plateau Central* regions and more than 30% in *Centre-Nord* region. Among the different techniques, stone lines are most widespread (65% of SWC equipped fields), and zaï implementation remains marginal (10% in total) except in *Centre-Nord* (23%). Earth buds/ridge backs are widespread in *Centre-Sud* region (36% of the equipped SWC fields) (EPA website, http://www.epa.gov.gh).

Table 6: Types and extent of SWC techniques per main crop.

Fields equipped with SWC		Main type of SWC
millet	20%	stone bunds
maize	16%	stone bunds
rice	18%	ridge back (bourrelets en terre)
cotton	10%	stone bunds
white sorghum	24%	stone bunds
red sorghum	18%	stone bunds

75% of intercropped fields equipped for SWC are cultivated with cowpea as secondary crop.

Box 1: Soil and Water Conservation Practices

Zaï **(*Tassa* in Niger)**

Description: Traditional planting pits.

Effect: rainwater use optimization, manure economy, rehabilitation of degraded land.

Extent: Traditionally, planting pits were used on a small scale to rehabilitate hardrock, barren land (zipélé), in which rainfall could no longer infiltrate in northern Burkina Faso (Yatenga). This technique extends nowadays southwards. Zaï functions best in areas with a minimum of 300 mm and a maximum of 800 mm rainfall (Roose et al., 1993). With less than 300 mm, the risk of crop failure becomes too big and with more than 800 mm the crop risks to get too much water. Moreover, the soil surface should be barren, flat and hard, in order to generate sufficient runoff. Digging pits requires substantial labor work, hence a relatively high population density would ease its spreading.

Technique: The dimensions of the pits reach a diameter of 20 - 30 cm with a depth of about 20 cm. It is dug during the dry season and fertilizer/manure is applied into the pit so that it directly benefits to the plant. The improved planting pits concentrate water and nutrients in one spot. The organic material used attracts termites that play a crucial role in improving soil structure by digging channels and digesting the organic matter and thus make nutrients more easily assimilable. About 2 to 5 years after implementing the zaï technique, farmers dig new pits in between the former ones, hence on some types of soils the area under zaï is converted after few years into a fertile land that can be tilled again with the plough or the hoe. This technique was developed initially in the early 80's by the Yatenga farmers themselves. Digging the pit demands considerable quantities of labor, about 300 person-hours per hectare. The number of pits in Yatenga ranges from 8,000/ha to 18,000/ha but it can reach up to 51,000/ha in other regions (Kaboré and Reij, 2004). *Efficiency:* it collects about 25% of runoff

Stone lines/bunds ("cordons pierreux")

Description: 1 to 3 rows of rough stone disposed along contour lines, i.e., perpendicular to the slope.

Extent: 100,000 ha of stone lines are installed in the *Plateau Central* since the beginning of the 80's.

Technique: 40 tons of stone are required to treat 1 ha of land with stone bunds (Reij et al., 2005).

Aims: Increase efficiency of water entering the field by reducing flow velocity, increasing infiltration and superficial storage.

Efficiency: 53% reduction in runoff, 39% limitation of peak flows that increases with clogging (runoff water decreases by 10 % the first year, and by 70% after 5-6 years (Fournier et al., 2000)).

Crop cycle is shorter, foliar development is earlier, yields increase by 30 % (Kambou and Zougmoré, 1996) and even 100 % if combined with organic matter application (Guillobez and Zougmoré, 1994).

On-farm efficiency is much lesser than the experimental one. The suppression of a stone may lead to gully formations. Stone lines are sometimes replaced by branches bunches, but their efficiency is limited.

Ridge back (ados)

Description: Contour earth bunds.
Technique: Easy to implement, but rapidly destroyed by intense rainfall unless it is planted with permanent cover. Slope must be < 3 % and soils neither clayish nor sandy, i.e., without water logging nor instability.
Extent: Central Plateau (Burkina Faso)
Effect : Rainwater infiltrates between ridges, while water excess is evacuated at the edges. It reduces erosion and increases infiltration.
Efficiency: Increases infiltration by 10 %, and yields by 30 %, limits inter-annual variability by reducing water stress.
They are all the more efficient as intercropping millet and pulses is combined with other techniques, such as mulching and manure application (+50 % and even 100 % for a manure application of 5 t/ha).

Mulching

Description: operation consisting in covering soil around plants with a protector material (straw, crop residues, dry grass…)
Technique: two tons of mulch per hectare covers only 7 to 10 % of soil surface.
Aim: reduce kinetic energy of raindrops and splash erosion
Effect: Reduces erosion: sediments flow decrease by 40 to 60 % (with 2 tons/ha of mulch) (Bielders et al., 1998).
Fertilizes soil (slow decomposition of culture residues).
Increase in organic matter rate and slow mineralization.
Development of termites and earthworms activity that keep soil surface mellow (Roose et al., 1992), which improves soil structure, increases roughness, and porosity.
Slowing down of runoff that favors rainfall infiltration (Anschütz et al., 1997).
Reduction of evapotranspiration that increases soil wetness (Anschütz et al., 1997).
Efficiency: Increase of yields by up to 3.5 or even 6 (Da, 2004). Nevertheless, the productivity increase does not always compensate the supplementary labor and time (3 to 5 times more) spent to collect residues and grass and to cover soil (Kaboré, 1994). Additionally, the on-farm mulch thickness is often inferior to recommendations, which tempers its positive effects.

Level permeable rock dams,

Description: long, low dams of loose stone constructed without a spillway, which are used to rehabilitate gullies.
Effect: Stabilization of the cropped area, increase of yields, Cultivated fields treated with SWC techniques have more trees than 10– 15 years ago, but the vegetation on most of the non-cultivated areas continues to degrade. Greater availability of forage for livestock is due to local regeneration of vegetation and residues from the greater crops production. Women and men invest more in livestock and livestock management has changed from extensive to semi-intensive methods. Farmers have improved soil fertility management, but more is needed to sustainably increase yields, stabilization of population, rise of GW levels (Reij et al., 2005).
Consequences: SWC has substantially increased the production of fodder (stover, herbs and pods), which makes it possible to increase livestock numbers; this requires however improved availability of water at the village level. Food deficits are smaller and in good years small surpluses are produced. This has freed up money for investment in livestock and this in turn leads to an increase in manure production. A rise of groundwater levels could also be imputed to SWC techniques. Very few case studies exist on the impact of SWC on poverty but it seems to be positive (Kaboré and Reij, 2004).

(2) Efficiency

The EPA data for Burkina Faso have been used to compare yields of fields with Zaï and without any anti-erosive method. Crops that were planted on Zaï fields were millet, sorghum and maize. We used the student test to compare the mean yields (with α=5%). The mean yields with and without Zaï did not show any significant difference in 2004.

However, yields on of formerly degraded parcels show significant increase with Zaï technique. Major impacts of SWC identified by Reij et al. (2005) on degraded lands include:

- significant increases in millet and sorghum yields,
- cultivated fields treated with SWC techniques have mores trees than 10-15 years ago while the vegetation of non-cultivated area continues to degrade,
- greater availability of forage for livestock, increased investment in livestock by men and women and a beginning of change in livestock management from extensive to semi-intensive methods,
- improved soil fertility management by farmers,
- locally rising ground-water tables,
- decrease in immigration,
- and a significant reduction in rural poverty.

Appropriate levels for research and technology transfer are the “resource domain”, which corresponds to homogeneous resource units (inland valleys…) for research on physical dynamics, and the “farming domain”, which corresponds to a farming system under a determined evolution (ex: cotton-based farming system under market-driven intensification), for applied research. Farming domains can hardly be mapped as a single farm may comprise several resource and farming domains. Research institutions need to clearly identify the resource and farming domain in their works, which will be useful for outscaling (Weber et al., 1996).

V. CHALLENGES OF RAINFED AGRICULTURE

Agriculture in the Volta basin has to face a major challenge, which is to ensure food security in a context of growing constraints. Food production must be increased to feed the cities, either by extending the cropped area or by increasing productivity. Employment and livelihoods must be maintained in rural areas in order to reduce migratory fluxes and fight against inequalities and poverty that primarily concerns rural areas (Bélières et al., 2002).

These challenges have to be placed in the context of climate change. The last report of the Intergovernmental Panel on Climate Change specifies its impacts (IPCC, 2007). One of the main challenges according to Koffi Annan, the former United Nations General Secretary, is to produce “more crop per drop”. Intensification seems unavoidable, but has to be done with techniques adapted to the local context (rainfall, soils, but also socio-economic background).

Objectives must include increasing yields or, if impossible in some area, at least stabilizing them. For this purpose, soil fertility must be restored while runoff and erosion processes must be stopped.

Agronomic conditions of research experimental work can seldom be reproduced by farmers, and recommendations are often quite far from reality. Therefore, on-farm research should be favored (Milleville, 2006; Hauchart, 2007) and should focus on the nexus between agriculture, social science and geography.

CICRED (2007) mentions the following constraints in North Togo:

- an unfavorable geo-climatic context which constrains the increase of agricultural productivity,
- a strong inequality of the production potential among localities,
- an excessive splintering of land (due to the land tenure system) and an unequal distribution among ethnical groups,
- a reduction of potential cropland due to the extension of natural reserves (fauna and flora),
- a very high fecundity which prevents the improvement of living standards.

Agriculture in the Volta basin is a crucial economic sector. It provides livelihoods for about 80% of the population. But in the coming years, it will have to face several challenges, in particular:

- produce on poor and degraded soils,
- guarantee sufficient food production in a context of increasing population,
- reduce farmers' vulnerability by decreasing inter-annual yield variability, within a context of climate change and variation of rainfall characteristics,
- increase yields while manual/traditional cropping practices are widespread.

A. Biophysical Constraints

1. Degrading environment

"About 55% of Africa's land area is unsuitable for agriculture. Only 11% of the continent, spread over many countries, has high soil quality that can be effectively managed to sustain twice the current population (Eswaran et al. 1997). Most of the remaining usable land is of medium or low potential, with at least one major constraint for agriculture. This land is at high risk of degradation under low input systems. By 1990 soil degradation was estimated to have affected 500 million hectares, or 17% of Africa's land (UNEP 1997). Susceptible drylands (arid, semi-arid and sub-humid aridity zones), covering 43% of Africa, are the worst-affected areas, impacting 485 million people (Reich et al. 2001). Approximately 65% of agricultural land, 31% of permanent pastures and 19% of forest and woodland in Africa were estimated to be affected by some form of degradation in 1990 (Oldeman 1994). The current situation is undoubtedly worse. Soil moisture stress inherently constrains land productivity on 86% of soils in Africa (Eswaran et al. 1997), but soil fertility degradation now places an additional serious human-induced limitation on productivity.

Agricultural systems with insufficient nutrient input on land with poor to moderate potential are the root cause of human-induced soil degradation in Africa. Although many farmers have developed soil management strategies to cope with the poor quality of their limited resources, low inputs of nutrient and organic matter contribute to poor crop growth and the mining of soil nutrients. Fertilizer use throughout the continent is by far the lowest in the world – less than 9 kg nitrogen per ha and 6 kg phosphorus per ha, compared with typical crop requirements of 60 kg nitrogen per ha and 30 kg phosphorus per ha. Mid-90's estimates show that every country in Africa had a negative nutrient balance in its soils. The amount of nitrogen, phosphorus and potassium added as inputs was indeed significantly less than the amount consumed by the plants or lost by erosion and leaching.

Soil fertility decline is associated with several simultaneous degradation processes feeding on each other to produce a downward spiral in productivity and environmental quality. For example, the combined effects of tillage and insufficient applications of nutrient and organic matter inevitably lead to a decline in soil organic matter. This reduces the retention of essential plant nutrients, breaks down soil physical structure and in turn diminishes water infiltration and the soil water storage capacity. Beyond this, African farmers face other degradation processes such as erosion, salinization and acidification." (Swift and Shepherd, 2007).

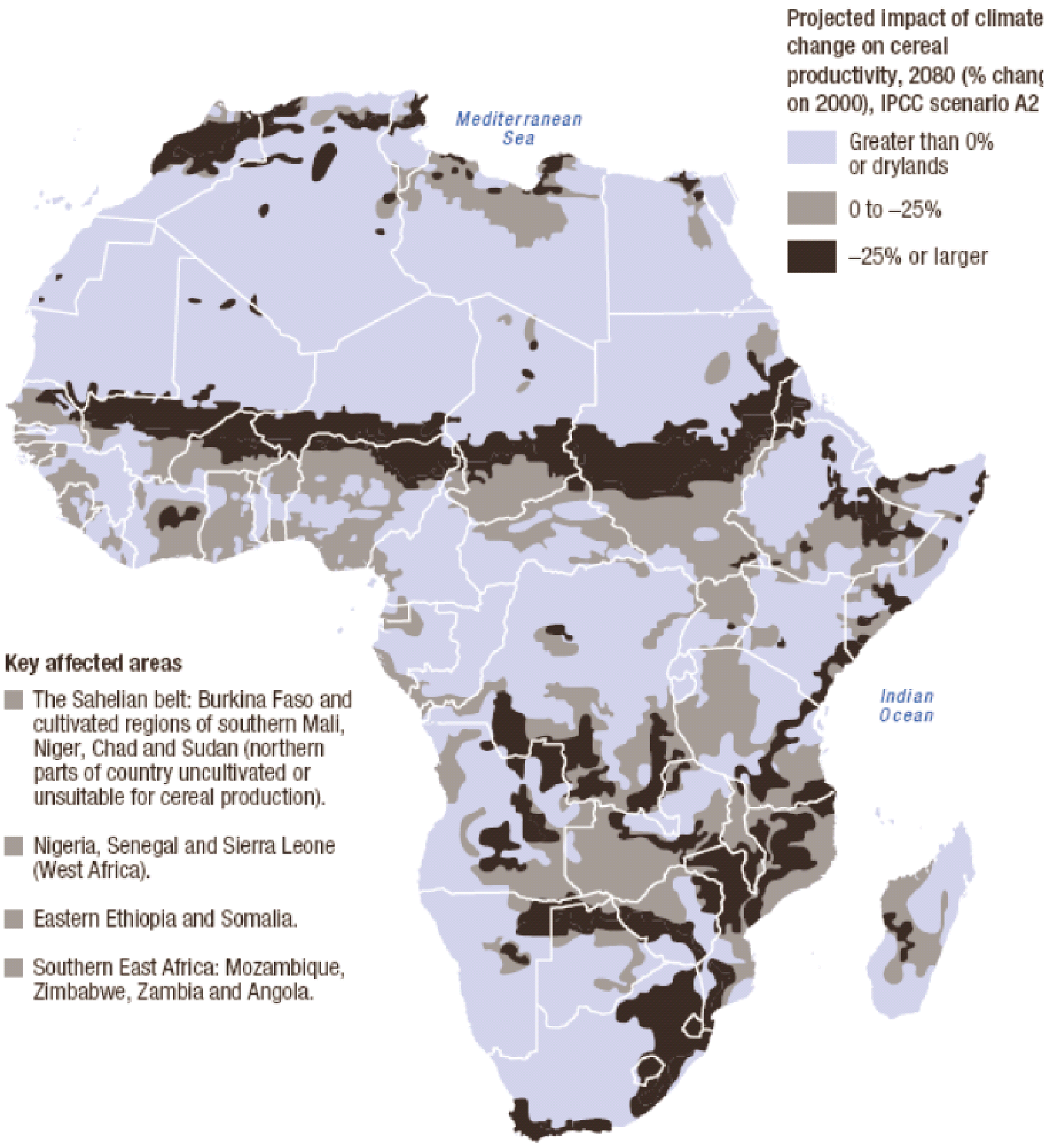
2. Coping with climate

Africa is considered as the most vulnerable continent. The impact of climate change on local populations may be aggravated by the multiplication of extreme events (droughts, floods). Some adaptation is taking place, but it may not be sufficient to face future change.

Sub-Saharian Africa will globally face a warmer and dryer climate inducing shorter growing periods and decrease both in crop yields and in cropped area (Third Assessment report of the IPCC). However regional predictions for West Africa are not unanimous, some suggesting a possible slight increase of rainfall before drier and more variable levels than today, other suggesting directly a drier climate.

Until 2020, 75 to 250 millions of people may lack water because of climate change itself. If the increase in water demand is also considered, it is obvious that growing number of water conflicts may take place (Intergovernmental Panel on Climate Change, 2007)

The following map shows that most of the Volta basin is likely to be affected by climate change, and that yields are likely to decline.



Note: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Source: Fischer and others 2005.

Figure 20: **Climate change threatens to reduce cereal productivity across much of Sub-Saharan Africa (source : Fischer et al., 2005, quoted in (IIED, 2007))**

B. Institutional and social constraints

1. Increasing demographic pressure

The population growth rate is very high. The annual population growth rate for the period 2000-2005 was 3.2% in Burkina Faso and 2.1% in Ghana. The share of the total population living in urban areas in 2005 was 18% in Burkina Faso and 48% in Ghana. (United Nations Statistics Division data).

Urbanization has been rapid in the last decades, with predictions for 2020 that 60% or more of the West Africa region population will be urban. Urban and peri-urban areas in West Africa have long exercised a very powerful influence over the neighboring hinterlands, spreading economic development through market relations. Yet this beneficial impact from improved access to markets is matched by a growing level of land insecurity (Toulmin and Gueye, 2003).

2. Limited manpower

Evidences show that labor availability and pressure to innovate grow along with increase in population density (Trench et al., 2007).

However social changes experienced by much of rural West African society lead to a fragmentation of large domestic groups into smaller family units, where principles of long-term reciprocity are replaced by calculations of shorter economic terms (Amanor, 1999). For example in eastern Ghana, young men used to work for free on the family's land, with the prospect of long term returns in the form of help with marriage costs, and increased access to land and family wealth over time. However, this implicit contract between elders and youth has disintegrated in many locations, expectations of both sides being unfulfilled. As a result, youths have withdrawn their labor services from family activities and prefer to work for cash on a neighbor's farm (Amanor, 2001; Toulmin and Gueye, 2003).

3. Traditional/legal land tenure system and social structures

In Burkina Faso, land tenure laws have been under review for several years. The country, as other countries in the Sahel, is struggling with the multiplicity of land-tenure systems that are *de facto* in effect: modern written law, Islamic law and multiple customary laws. As a result, conflicts arise where people apply different tenure systems to the same resources. In Burkina Faso there is uncertainty about how the law will change, together with an increase in population pressure in the western cotton belt regions and immigration. This results in land-owners attempting to renegotiate the long terms of land leasing in favor of immigrants so as to secure their ownership. Also there is rapid land commoditization , especially near urban centers where lands are bought speculatively by wealthy investors (Trench et al., 2007).

Gaining secure access to land is of particular importance to poorer people, whose livelihoods depend on balancing a range of different activities, including negotiating access to a plot of land and being able to use the local commons. These rights are often not full property rights but various forms of secondary access. Yet such rights are increasingly subject to threat, as land values raise and new interests enter the land arena.
Poor tend to be particularly vulnerable in areas undergoing rapid change, such as on the peri-urban fringe and in cash-crop producing zones. In western Burkina Faso, arrangements for accessing land have shifted substantially from long-term loans to shorter term rental, with payments either in cash or through provision of services (labor, ploughing) (Toulmin and Gueye, 2003).

4. Liberal and global economy

West African farmers are increasingly exposed to the diverse consequences of globalization.Producers of the Sahelian countries are actors in global markets but are largely unaware of this, and largely powerless to influence the global situation. As producers, farmers and pastoralists are vulnerable to falls in the international market (often caused by dumping from countries where production is subsidized). Production costs are no longer covered by the market price and farmers are at risk of losing their assets to cover new debts. As consumers, Sahelian farmers and pastoralists may find that costs are lower, but their decreasing income undermines their purchasing power (Trench et al., 2007).

At West Africa's current level of economic development, agriculture remains central to GDP, employment, livelihoods and export revenue. Such dependence is likely to continue in the foreseeable future. Further agricultural development is the best option for generating increasing incomes, diversification of the economy and reduction in poverty. Farmers need a decent return on their labor and capital if they are to continue investing effort in further intensification of agriculture.

Yet the broader global context is making such a growth pathway increasingly difficult to tread. Family farms, which make up the vast majority of holdings in West Africa, have demonstrated great flexibility and capacity to adapt to new circumstances, but adaptation has its limits. The category "family farming" covers a wide range of agricultural operations from highly market-oriented farms, closely linked into global markets, through mixed market and subsistence-based farm households, to those who are barely scraping a living from the land (Toulmin and Gueye, 2003).

5. Access of farmers to markets

Physical access to markets is extremely poor and therefore very costly. Even in the areas with the highest concentration of people, most rural communities are extremely isolated due to a weak road and rail network.
Lack of access to markets is often cited as a constraint on production and therefore on livelihoods. Poor roads severely constrain the development of market gardening –lack of vegetables in the market affects nutrition status and health (Trench et al., 2007).

African rural people, especially the poor, often say that they cannot improve their living standards particularly because of a difficult access to market, i.e., agricultural inputs, consumer goods and selling opportunities.

Until a decade ago, major markets of smallholder farmers were organized by governments, and exchanges were not critically influenced by farmer knowledge and organization. Nowadays the situation has changed radically almost everywhere. Smallholder farmers no longer have an assured market for their produce at fixed, pan-territorial prices, which often represented a large tax on the product value. Similarly, they no longer face a predictable supply situation for inputs and presently, they may not be able to afford buying what becomes available.

Market access has become a critical determinant of farmers' production systems: those who live close to better roads and have more frequent and direct contacts with the market are willing to produce more systematically for the market, while those with poor market access have little incentive to produce crops other than those required for domestic consumption.

By and large, smallholder farmers are ill equipped to extract the maximum from the new market relations that they face. They confront not only an uncertain production environment, but also enormous constraints in physically accessing markets – these are typically distant, transportation costs are high and, in many cases, there are few buyers.
Poor African farmers are also constrained by lack of (*i*) information on the markets, (*ii*) business and negotiating experience and (*iii*) collective organization which would empower them to interact on equal terms with larger and stronger market intermediaries (NEPAD, 2002).

Producers' Organizations (POs) emerged as a key strategy for small-scale producers to access, compete in and increase their bargaining power in the market. However, promoting POs has become at the same time a 'fashionable' economic development strategy. Hence, successes and limitations of such organizations should be scrutinized, especially when POs are formed in response to external agencies rather than producers' own initiative (Penrose-Buckley, 2007).

C. Out of Poverty

As agriculture remains the economic base for the majority of poor and as it constitutes a key economic sector in most African countries, its importance in poverty reduction and sustainable development is fundamental. Most of agricultural productions, in particular staple food, come from small-scale farms. Moreover, as much of agriculture is low-input, rainfall dependent, the use made of natural resources by agriculturalists is crucial in determining the sustainability of production systems and of biodiversity (EU Discussion Paper 2007).

Much of the past agricultural output growth has been achieved through expansion in the use of production factors (land, labor, livestock), particularly through the extension of crop land, pastures. The occupation of marginal or unsuitable land for agriculture has had negative impacts on natural resource qualities and contributed to lower land productivity. However, a drastic acceleration in growth of productivity is required in the next decade to achieve the MDG targets[4]. Small farmers and staple food production should be specifically targeted for a positive impact on food security and rural poverty alleviation. Prospects also exist for significant productivity improvement through irrigation and through improved functioning of input markets (including finance, and land) (EU Discussion Paper 2007).
Obtaining a rewarding selling price remains a major challenge for African farmers. Therefore priority will be to improve marketing processes at the national and regional levels, linking producers to remunerative markets (which may be remoter), and ensuring that marketing structures favor fair price (EU Discussion Paper 2007).

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[4] Agricultural development contributes directly to reaching the first Millennium Development Goal: eradication of extreme poverty and hunger, as well as the seventh: ensure environmental sustainability

Agriculture can be a cause of natural resource degradation, when production methods are unsustainable, while it suffers at the same time from this degradation, with direct effects on productivity and conflicts over resource access and use. Moreover, maintenance of biodiversity levels is the long-term interest of agriculture, since it will provide a genetic base for productivity improvement and diversification (new crops, new applications). Good management of natural resources is therefore important for economic, socio-political and environmental reasons. A number of factors are keys to success: positive economic returns from a sustainable use of natural resource, incentives and capacity building for sustainable practices and, above all, effective management regimes, policies and regulations on access and usage (EU Discussion Paper 2007).

Most of Africa's agricultural producers are exposed to price instability, natural disasters, diseases, conflicts and uncertainty on access to resources and markets, often without recourse to adequate means to manage these risks. Many small farmers have a narrow asset base, which makes them extremely vulnerable to adverse conditions, requiring external safety nets (family, migration, government intervention) for survival. Moreover, agricultural growth in general and a diversification of livelihoods reduce risk at community and sector level (EU Discussion Paper 2007).

VI. RESEARCH OPPORTUNITIES

Much of the knowledge and many of the technologies developed in the past decades have not been successful at farmers' level and have faced insufficient adoption rates, due to a lack of dissemination and/or to inappropriateness, which in turn was due to a "supply driven" approach. In order to enhance the productivity level of small-holders, there is a need to shift the research paradigm towards a "demand driven" approach. Moreover, there should be an increased investments in research, which would be at the same time sufficiently site-specific and generating knowledge that can be up-scaled (generation of global/international public goods). Farmers and their organizations should be totally involved in the research-to-development continuum, including monitoring, evaluation and impact assessment. In other cases, e.g. for many African staple foods, scientific breakthroughs are required to reverse the underinvestment in public sector research and to establish targeted partnerships with the private sector, international agencies and research centers. A focus on staple food production is essential since a stable and increasing yield for these crops generally have a significant effect on poverty reduction, both rural and urban (EU Discussion Paper 2007).

Recapitulatif:

CONCLUSION

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