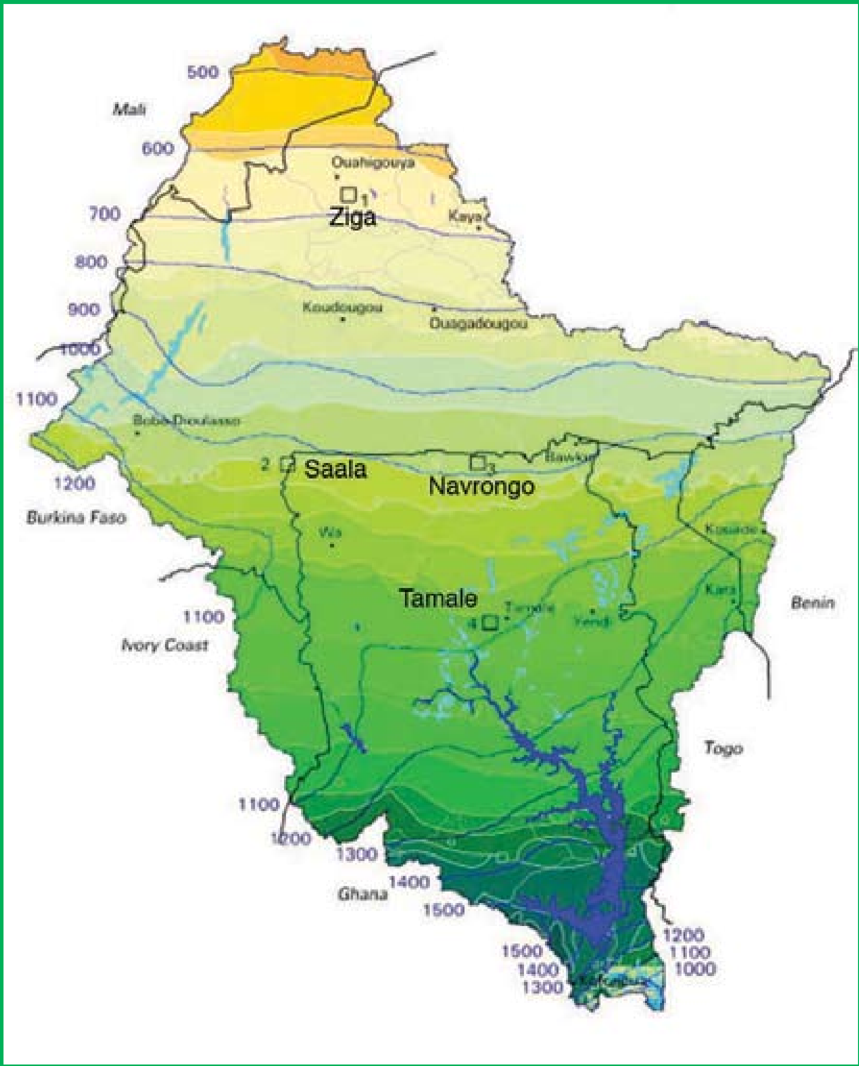
Synthesis of soil, water and nutrient management research in the Volta Basin



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Content

Preface

The majority of the population in the Volta basin is resource poor smallholders who rely on rainfed agriculture for their livelihoods. However, the average rainfall of 1000 mm per year, which seems to be enough for crop production in the region, is quite variable, thereby making rainfed agriculture a risky enterprise. The distribution of rain over the growing season has also been noted to be another bottleneck in agricultural production. Especially the onset of the rainy season is very unreliable and the frequent periods of drought (10-20 days) within the season cause significant crop damage. Furthermore, there has been a decrease in rainfall in most of the region since the 1960's when compared to the 20th century average.

Food security is under threat in the entire Volta basin due to the low water availability, increasing soil degradation and the dwindling farm sizes. Crop failure results quite often as a result of low and poorly distributed rainfall, increasing land degradation caused by inappropriate management practices like plowing and intensive hoeing causing surface crusting, soil compaction, decrease in soil organic matter and hard-pan formation. All these have contributed to the inefficient use of the precious and scarce water available.

Water and nutrient use efficiency is therefore the key to improving agricultural and livestock productivity in the Volta Basin. Improving water productivity will mean getting more value from every drop used for crops, fish, forests or livestock while maintaining or improving ecosystems services. More importantly past research have shown that only 10% of the rainwater is used by the crop, the majority of it being lost to evaporation

In the past, international and national agricultural research systems have developed high-yielding cereal and legume varieties that respond to different rainfall regimes. However, although it is known that an integrated approach to water, crop and nutrient management is essential for increasing and stabilizing crop production and optimizing inputs use, there is a dearth of empirical studies on such interactions. Furthermore, majority of research has been conducted with little participation of farmers and rural communities who are the ultimate users and beneficiaries of research results. This has largely limited the adoption of agricultural technologies by small scale farmers, especially women who constitute the majority of farming population. We now know that farmers and rural communities are searching for new ways to intensify and diversify their systems to meet their food security needs as well as generating income, and seize upcoming market opportunities. A win-win situation can occur when a systems research integrates germplasm, crop, nutrient, soil and water management, with explicit focus to empowering farmers and rural communities to take advantage of market opportunities to raise their incomes and invest in better management of their resources. New tools such Geographical Information Systems (GIS) and models can be very useful in facilitating the analysis of these integrated systems. The DSSAT-CENTURY (Decision Support for Agro technology Transfer) cropping systems models enables the analysis of how different soil, climatic and land management strategies affect the yield of a range of crops. On the other hand, participatory research approaches have been found very effective in enhancing the adoption of technologies, empowering rural communities and promoting equity.

The project entitled "Enhancing rainwater and nutrient use efficiency for improved crop productivity, farm income and rural livelihoods in the Volta basin" is funded by the Challenge Program on Water and Food (CPWF) and led by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). It is designed to address the major constraints that are encountered by small-scale resource-poor farmers in the Volta Basin, who rely on rain fed agriculture for their livelihoods. The overall research hypothesis is that using a systems approach that integrates water use efficiency, soil and nutrient management, and improved germplasm together with market opportunity identification and building rural communities capacity will result in significant benefits to the rural poor and the environment.

As one of the major outputs of the project, this book which contains 16 chapters covers a range of topics related to natural resource management in the Volta basin. The authors have made a good synthesis and review of the soil, water, crop and nutrient management research in the Volta basin. The biophysical and socio-economic characteristics of the Volta Basin are described extensively in chapter 1. Chapters 2 to 16 contain the syntheses of the research and development work that was conducted, over the years, by various research organizations in Burkina Faso and Ghana that are the participating countries in this project. From this information, constraints to agricultural productivity and opportunities for complementary research were identified. The book provides excellent background information to guide future research activities in the Volta basin.

As editors of this synthesis book, we would like to thank all the authors for their efforts in pulling together this vast amount of information on the research work on soil, water, nutrient and crop management in the region. We wish to express our sincere gratitude to the reviewers for their invaluable comments and suggestions which helped the authors to improve on their papers. We are most grateful to the Challenge Program on Water and Food (CPWF) for providing the necessary funds for this project and for the publication of the book.

Andre Bationo, Ramadjita Tabo, Boaz Waswa, Jeremiah Okeyo, Job Kihara, Mathias Fosu and Seraphine Kabore

Foreword

Throughout the world, water scarcity constitutes one of the most pressing issues that humanity faces today. Sufficient water supply is critical for human health, agriculture and poverty reduction. However, this resource is in considerable shortage, both in terms of availability and quality and the most impoverished inhabitants of developing countries are the most vulnerable, with very limited coping strategies.

The majority of the population living in the Volta Basin comprises resource poor smallholders who depend on rainfed agriculture for their livelihoods. However, the average rainfall of 1000 mm per year, which seems to be enough for crop production in the region, is quite variable over the cropping season, thereby making rainfed agriculture a risky enterprise. Furthermore rainfall amount has been decreasing in the most parts of the region since the 1960's compared to the 20th Century average. In addition to the erratic, low and unpredictable rainfall over the years, other factors contributing to water becoming a scarce resource in the Volta Basin are the increasing human population and livestock pressure, and the growing competition over the use of water for generating hydroelectricity. To meet the needs of the fast growing population, more food must be produced with less water.

In the entire Volta Basin, thus, food security is under threat due to the low water availability, increasing soil degradation and the dwindling farm sizes. Crop failure has not been the consequence of only low rainfall but also due to the effect of soil degradation caused by inappropriate management practices like plowing and intensive hoeing causing surface crusting, soil compaction, decrease in soil organic matter and hard-pan formation. All these have contributed to the inefficient use of the precious water available.

Declining water quantity and quality has become a critical limiting factor to agricultural productivity. More importantly, past research have shown that only 10% of the rainwater is used by the crop, the majority of it being lost to evaporation. Water use efficiency holds the key to improving agricultural and livestock productivity in the Volta Basin. The solution to the water crisis could be found in how water is developed and managed to improve its productivity in agriculture. In a broader sense, improving water productivity will mean getting more value from every drop used for crops, fish, forests or livestock production while maintaining or improving ecosystems services.

This project entitled "Enhancing rainwater and nutrient use efficiency for improved crop productivity, farm income and rural livelihoods in the Volta Basin" is funded by the Challenge Program on Water and Food (CPWF) and coordinated by the International Crops research Institute for the Semi-Arid Tropics (ICRISAT). It is designed to address the major constraints that are encountered by small-scale resource-poor farmers in the Volta Basin, who rely on rain fed agriculture for their livelihoods.

This book, which is one of the outputs of the project, presents a synthesis and review of the past work on soil, water, crop and nutrient management in the Volta Basin in general and in Ghana and Burkina Faso, the two project sites, in particular. The diverse topics covered in the book, contributed by leading researchers in the region, will provide a good background information and reference document that will guide the future work on resource management intervention in the project study countries. The authors and editors are to be commended for pulling together a wide range of research results from the past work in this area of soil, water, nutrient and crop management.

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Chapter 1

General Characteristics of the Volta Basin

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Abstract

The Volta Basin covers an area of about 400,000 km^2 of the semi-arid and sub-humid savanna of West Africa. This basin, which has a main channel of 1400 km, lies mainly in Ghana (42%) and Burkina Faso (43%), with minor parts in Togo, Côte d'Ivoire, Mali, and Benin. The region is poor; with a per capita income around US$ 1100 per year while the population growth rate is almost 3% per year. Although service and mining sectors contribute to the economic growth of most of these states, agriculture is by far the most important sector. Thus economic growth could be achieved with increased agricultural productivity. The majority of the population in the basin is small-scale farmers who rely on rain-fed agriculture for their livelihoods. However, the average rainfall of 1000 mm per year, which seems to be enough for crop production in the region, is very variable and this makes rain-fed agriculture a risky enterprise. The distribution of rain over the growing season has also been noted to be another bottleneck in agricultural production. Apart from the erratic, low and unpredictable rainfall over the years, other factors contributing to water becoming a scarce resource in the Volta basin are the increasing population and livestock pressure, and growing competition over the use of water for generating hydroelectricity. The entire Volta Basin is faced with a problem of food insecurity threat due to the low water availability, increasing soil degradation and the dwindling farm sizes. Crop failure has not been the consequence of not only low rainfall but also due to the effect of soil degradation caused by inappropriate management practices like plowing and intensive hoeing causing surface crusting, soil compaction, decrease in soil organic matter and hard-pan formation. All these have contributed to the inefficient use of the precious water available. A survey of the Volta Basin reveals that the region is characterized by highly complex agro-ecological and socio-economic conditions which are the drivers of agricultural production.

Key words: *Climatic conditions, geology and soils, landuse, vegetation, Volta basin*

Résumé

Le bassin de la Volta couvre une superficie d'environ 400.000 km2 de la savane Ouest africaine semi-aride et sub-humide. Ce bassin qui a un canal principal long de 14.000 km couvre principalement le Ghana (42%), le Burkina Faso (43%), et d'autres petites parties au Togo, en Côte d'Ivoire, au Mali, et au Bénin. La région est pauvre avec un revenu d'environ 1100 dollars US par habitant et par an; pendant que la croissance de la population est d'au moins 3% par an. Malgré que les autres services et le secteur minier contribuent à la croissance économique des différents pays, l'agriculture est de loin le plus important secteur. Ainsi, la croissance économique ne pourra se faire que lorsque la productivité agricole est augmentée. La majorité de la population dans le bassin est composée de petits producteurs qui tirent leur subsidence de l'agriculture pluviale. Les 1000 mm de moyenne pluviométrique annuelle qui devraient suffire pour une bonne production dans la région, sont très variables; ce qui fait de l'agriculture pluviale une entreprise a haut risqué. La distribution des pluies pendant la saison constitue un autre blocage dans la production agricole. A part la rareté, la faiblesse et l'incertitude de la pluviométrie au cours des années; les autres facteurs faisant de l'eau une ressource rare dans le bassin de la Volta sont sans doute la pression de la population et du chaptel ainsi que la compétition croissante de l'utilisation de l'eau comme source hydroélectrique. Le bassin entier fait face au problème d'insécurité alimentaire, conséquence de la faible disponibilité de l'eau, la dégradation des sols et la diminution des surfaces cultivables. La perte de la production agricole n'est pas seulement la conséquence d'une faible pluviométrie mais aussi l'effet de la dégradation des sols causée par des pratiques culturales inappropriés telles que le billonnage et le labour intensif causant des cuirasses, la compaction du sol, la réduction de la matière organique et la formation d'autres anomalies. Tous ces facteurs ont contribuent à une utilisation inefficace de l'eau disponible. Une enquête sur le bassin de la Volta a revelee que la région est caractérisée par d'importants complexes agrobiologique et socio-économique qui constituent le moteur de la production agricole.

Mots clés: *conditions climatiques, geologie et sols, utilization du sols, végétation, Bassin de la Volta.*

Location and Area

The Volta Basin is one of the major river basins in Africa with significant contribution to regional development. The basin is located in West Africa (Figure 1) and lies within Latitudes 5° 30 N and 14° 30 N and Longitudes 2° 00 E and 5° 30 W. It covers an area of approximately 414,000 kmi^2 in the sub-humid to semi-arid West-African savanna zone including parts of Burkina Faso, Ghana, Togo, Mali, Benin and Côte d' Ivoire. The percentage share of basin area per country is given in Table 1

Table 1: Share of total basin area per country

Country	Share of basin area (sq. km)*	Share of basin area (%)	Fraction of country area (%) in Basin
Benin	14,360	3.5	12.4
Burkina Faso	174,800	42.2	63.4
Ghana	166,100	40.1	69.3
Côte d' Ivoire	13,850	3.3	4.3
Mali	19,850	4.8	1.6
Togo	25,040	6.0	43.7
Total	414,000	100.0	

**spherical coordinates*

A dominating feature of the basin is Lake Volta, which is the largest man-made lake in the world in terms of surface area. The lake reservoir itself has a surface area of about 8,500 km^2, an average depth of about 18.8m and a shoreline of about 5,500 km, approximately (4% of total area of Ghana). The lake was created to generate hydropower at Akosombo and Kpong (1060MW), which is 100km north of its estuary.

Figure 1: Map of the Volta Basin

Topography

The Basin is flanked by a mountain chain on its western-most section. From the sea and northeastwards rises the Akwapim ranges, followed by Togo Mountain, Fazao Mountain, and the Atakora ranges in Benin. The Kwahu plateau branches northwest after the Akosombo Gorge. The only other significant relief on the western part of the Basin is the plateau of Banfora.

The Basin in general has a low relief with altitudes varying between 1 and 920 m. The average mean altitude of the Basin is approximately 257 m, with more than half the Basin in the range of 200-300 m. The global slope index is between 25 and 50 cm/km. Some of the characteristics of the relief are shown in Table 2. The Volta sub-basins comprise the White, the Black Volta, the Daka and the Oti basins. The local relief of the White Volta is about 400m with the maximum altitude of around 600m in the Gambaga hills in the northeast. There is considerable variation in local relief of the Black Volta, varying from 150m – 300m and increasing from the south to the north. The main Volta is generally below 150m with a few areas around the rim of the basin attaining altitudes of more than 300m above sea level. The Daka is not much more than about 150m above sea level.

Table 2: Minimum, average, and maximum altitude of the sub-basins

Elevations at MSL (m)	Black Volta	White Volta	Oti	Main Volta
Minimum	60	60	40	1
Maximum	762	530	920	972
Average	287	270	245	257

Source: Moniod et al. (1977)

Vegetation

Vegetation of the Volta Basin is highly diverse ranging from the dry shrub- and grasslands in the north, through savanna to the intensive croplands and moist forests in the south. The vegetation types are closely related to the rainfall patterns across the basin area. Parts of Mali and northern Burkina Faso are dominated by Sudanian woodlands and constitute up two 28% of the total basin area (Table 3). The central part of the basin mainly consists of savanna vegetation covering parts of southern Burkina Faso, Togo, Benin, Côte d' Ivoire and most of Ghana. It consists over 30% of the basin area. The central and southern parts of Ghana, parts of Côte d' Ivoire and Togo are dominated by croplands which were initially savanna but have been extensively deforested to give way for crop cultivation. The southern and coastal parts of Ghana consist of intensive croplands, tropical rainforests and mangrove forests. The spatial distribution of the various vegetation types of the Volta basin is shown on Figure 2.

Table 3: The Vegetation of the Volta Basin

Land Cover Class	Share of basin area (sq.km)	Share of basin area (%)
Shrubland / Grassland	7,974.4	1.92
Woodland / Grassland Mosaic	23,303.8	5.62
Woodland / Cropland Mosaic	32,439.5	7.83
Sudanian Woodland	117,835.0	28.43
Transitional Sudanian Forest	13,006.8	3.14
Savanna	114,660.8	27.66
Woody Savanna	10,219.6	2.47
Deforested Savanna with Crops	68,053.2	16.42
Secondary Tropical Forest	11,148.6	2.69
Tropical Rainforest	3,096.8	0.75
Mangroves / Swamps, Forest	696.8	0.17
Barren or Sparsely Vegetated	2,942.0	0.71
Intensive Cropland	3,484.0	0.84
Water Bodies	5,651.7	1.36
Total	414,513.0	100

Data source: NASA/USGS, 2003.

Climatic Conditions

The climate of the Volta Basin, surrounding countries and the rest of tropical West Africa, is dominated by the movement of the Inter Tropical Convergence Zone (ITCZ), which is the region where the hot, dry harmattan air mass from the Sahara in the North meets the cool, moist monsoon air from the South Atlantic. The ITCZ is characterized by vigorous frontal activity and its movement controls the amount and duration of rainfall. Normally from December to February, the front lies across the Gulf of Guinea and the dry harmattan prevails over all the countries across the Volta Basin and the regions remains relatively dry over this period. Between March and November, the ITCZ moves across the basin in a complex fashion crossing some areas twice, which results in a distinctly bimodal rainfall pattern, highly significant in Ghana than the rest of the basin countries. At higher latitudes the interval between the two peaks decreases until at the limit only a single peak is evident.

Rainfall

Three types of climatic zones can be identified in the region: the humid south with two distinct rainy seasons; the tropical transition zone with two seasons of rainfall very close to each other; and, the tropical climate, north of lat 9° N, with one rainfall season that peaks in August. Average annual rainfall varies across the basin from approximately 1600 mm in the southeastern section of the basin in Ghana, to about 360 mm in the northern part of Burkina Faso. Table 1.4 shows the average annual rainfall, evapotranspiration, and other hydrometeorological parameters in selected stations from different sub-basins in the Basin.

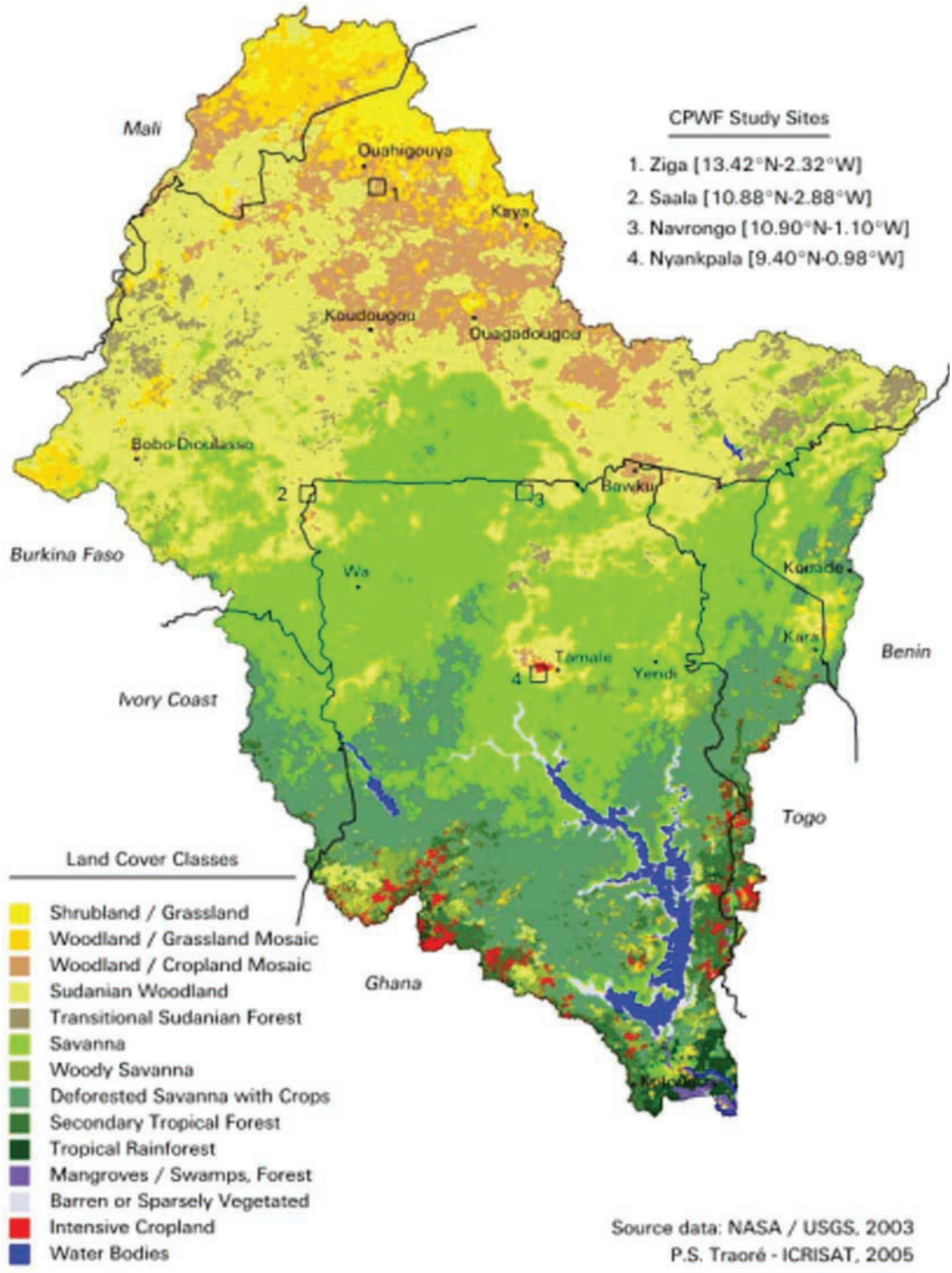

Figure 2: Map of vegetation types of the Volta basin.

Table 4: Rainfall, evapotranspiration, temperature, and relative humidity for selected stations

Volta Basin sub-system	Rainfall (mm)	Coeff. of var.	Potential evapotrans. (mm)	Temp. ^{0}C	Relative humidity %
Black	1023.3-1348.0	0.17-0.23	1450.0-1800.0	25.0-27.8	59-77
White	929.7-1054.2	0.16-0.20	1650.0-1968.0	28.0-28.6	54-68
Daka	1150.0-1350.0	0.17-0.18	1625.0-1750.0	27.4-27.6	63-70
Oti	1050.0-1500.0	0.18-0.20	1550.0-1850.0	27.0-27.8	62-72
Lower	876.3-1565.0	0.17-0.35	1450.0-1800.0	23.5-28.1	6-83

In the bimodal area in the south, the peak rainfall periods are June/July and September/October. In the north, the maximum rainfall month is normally September. The rainfall reduces eastwards and northwards to about 800 and 1,000 mm, respectively. Variations in average rainfall and evaporation in the different riparian countries and area covered are shown Table 5. Evaporation in the basin is relatively high especially in the Sahelian zone. In Burkina (43% of the basin), the lowest record is about 1,900mm/yr^{-1}. In the Volta Basin of Ghana, the potential evapotranspiration varies from a minimum of 1,450 mm per annum in the Black Volta sub-basin to a maximum of 1,968 mm per annum in the White Volta sub-basin.

Table 5: Rainfall and evaporation for selected stations in Volta

Country	Area of Volta Basin (km^2)	Upstream Riparian countries	Average annual rainfall (mm)	Average annual evaporation (mm)
Ghana	165,830	Burkina Faso, Mali,Togo, Côte D'Ivoire, Benin	1,320	1,415
Côte D'Ivoire	9,890	Burkina Faso	1,358	1,486
Togo	25,545	Burkina Faso, Benin	1,305	1,697
Burkina Faso	171,105	Mali	950	2,130
Benin	13,590	Burkina Faso, Togo	1,294	1,400
Mali	12,430	None	685	3,015

In recent years, a number of changes in the precipitation patterns in some sub-catchments in the Volta basin have been observed. For example, reductions in rainfall and run-off amounts have been evident since the 1970s (Opoku-Ankomah, 2000). Some areas that used to have bi-modal type of rainfall have only one mode as the second minor season has become very weak or non-existent. This situation means that rainfed agriculture can only be carried out once instead of twice a year. In Burkina Faso, the Volta basin stretches into three climatic zones:

1. the Sudan zone with an annual rainfall between 900 and 1,200mm distributed on average over 74 rainy days. It is located below the 11° 30'N parallel
2. the Sudano-Sahelian zone with an annual rainfall between 600 and 900mm on average over 43 rainy days, located between the 11° 30'N and 14oN parallels
3. the Sahelian zone located above the 14°N parallel with a mean annual rainfall between 300 and 600mm over 38 rainy days.

In the Sahelian zone, the rainy season lasts for about 3 months. It lasts 4 to 5 months in the Sudano-Sahelian zone and 6 to 7 months in the southern part of the Sudan zone. Dominant winds blow eastwest from January to March which is the harmattan season. Over the past 40 years, the rainfall amount has been decreasing leading to severe droughts during the 1970s and 1980s and only a slight recovery in 1985-1995. As a consequence of this instability in the rainfall pattern most of the rivers have dried up, most of the land cover has been degraded, crop failure has increased and the water table has been drawing down. This has led to a shift of the climatic zones in a southerly direction. Consequently most of the Volta basin in Burkina Faso is now located in the Sahelian and Sudano-Sahelian zones.

Table 6: Rainfall and length of the growing season

Agro-ecological zone	Mean annual rainfall (mm)	Growing period (days)	
		Major season	Minor season
Rain forest	2200	150-160	100
Deciduous forest	1500	150-160	90
Transitional	1300	200-220	60
Coastal	800	100-110	50
Guinea savanna	1100	180-200	-
Sudan savanna	1000	150-160	-

The total amount of rainfall received in an area and the distribution determines the length of the growing period. In general, the length of the growing period in the Volta Basin ranges from around 60 days in the north to over 300 days in the south (Table 6 and Figure 3).

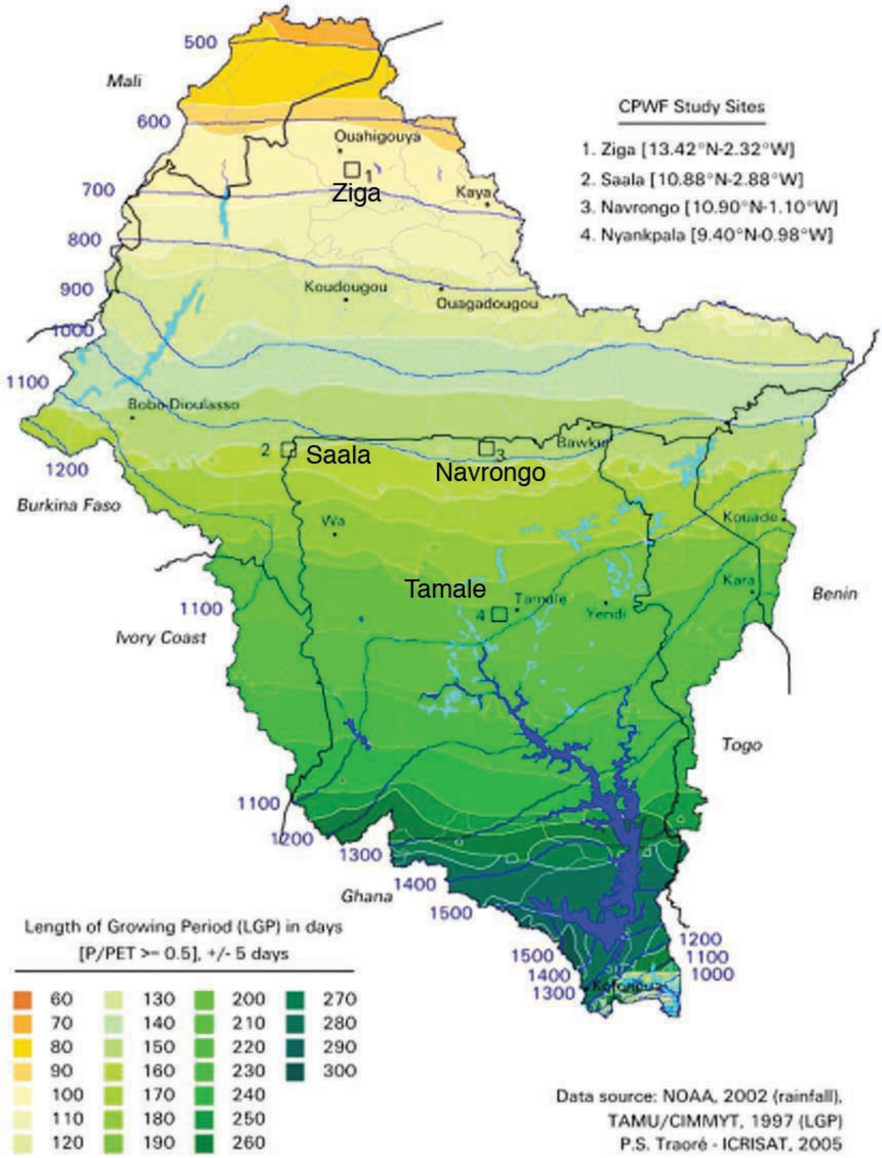

Figure 3: The Agro-Climate of the Volta Basin

Temperature and humidity

The annual mean temperatures in the Basin vary from about 27° C to 30° C. Daily temperatures can be as high as 32° C - 44° C, whereas night temperatures can be as low as 15° C. The humidity varies between 6% and 83% depending on the season and the location. Figure 4 shows the spatial distribution of temperatures in the Volta Basin. Generally, temperatures are higher in the upstream of the basin and decreases in the downstream.

In Ghana, Côte d' Ivoire, Togo and Benin, the mean temperatures never fall below 24° C. This is explained by the fact that all these countries lie in cross proximity of the equator. The hottest month of the year is March-April and the coolest is August. The southern sections of Ghana are more humid than the north. In the coastal area of Ghana the relative humidity are 95-100% in the morning and about 75% in the afternoon. In the north, and the other countries values can be as low as 20-30% during the harmatan period and 70- 80% during the rainy period.

In Burkina Faso and Mali, the mean temperature in the Sahel zone is always higher than 29°C while in the Sudano-Sahelian zone it lies between 28°C and 29°C and in the Sudan zone below 28°C. The seasonal variation in temperatures is characterized by four periods: two extremely hot periods and two relatively cool periods. The first hot period is in March-April with average maximum temperatures of 37°C and 41°C in the south, centre and north of the basin respectively, while the average minimum temperatures are 24°C (south), 25°C (centre) and 26°C (north). The second hot period occurs immediately after the rainy season. It is not as hot as the first, with average maximum temperature of 34°C, 36°C and 38°C in the south, centre and north respectively. Minimum temperatures vary between 21°C and 22°C.

Relative humidity can reach a maximum of 80% in August which is the wettest month of the rainy season. There are sometimes heavy falls of dew, especially in the south where levels of between 0.8mm and 1mm have been recorded. Total evaporation in August is generally lower than 100mm. From November to April relative humidity in Burkina is about 50%. Maximum pan evaporation (>400mm) is observed during March-April.

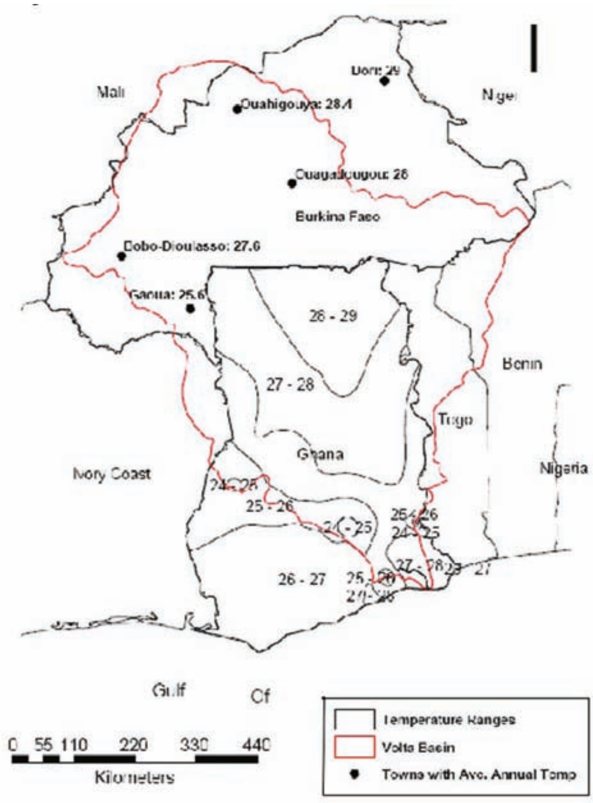

Figure 4: Spatial distribution of temperature in the Volta Basin

Geology and Soils

Geology

The geology of the main Volta is dominated by the Voltaian system (Figure 5). Other geological formations include the Buem formation, Togo series, Dahomeyan formation, and Tertiary-to-Recent formations. The Voltaian system consists of Precambrian to Paleozoic sandstones, shales and conglomerates. The Buem series lies between the Togo series in the east and the Voltaian system in the west. The Buem series is comprised of calcareous, argillaceous, sandy and ferruginous shales, sandstones, arkose, greywacke and agglomerates, tuffs, and jaspers. The Togo series lies to the eastern and southern part of the main Volta and consists of alternating arenaceous and argillaceous sediment. The Dahomeyan system occurs at the southern part of the main Volta Basin and consists of mainly metamorphic rocks, including hornblende and biotite, gneisses, migmatites, granulites, and schist.

The Oti Basin is underlain mainly by the Voltaian system, the Buem formation and the Togo series. The White Volta Basin is composed of the Birimian system and its associated granitic intrusives and isolated patches of Tarkwaian formation. The other significant formation is the Voltaian system. The Birimian system consists of metamorphosed lavas, pyroclastic rocks, phyllites, schists, tuffs, and greywackes.The Black Volta Basin consists of granite, the Birimian and Voltaian systems, and, to a minor extent, the Tarkwaian system. The Tarkwaian formation consists of quartzites, phyllites, grits, conglomerates, and schist. The underlying rocks of the Basin have no inherent porosity, so groundwater storage occurs only in fractured zones of the rock.

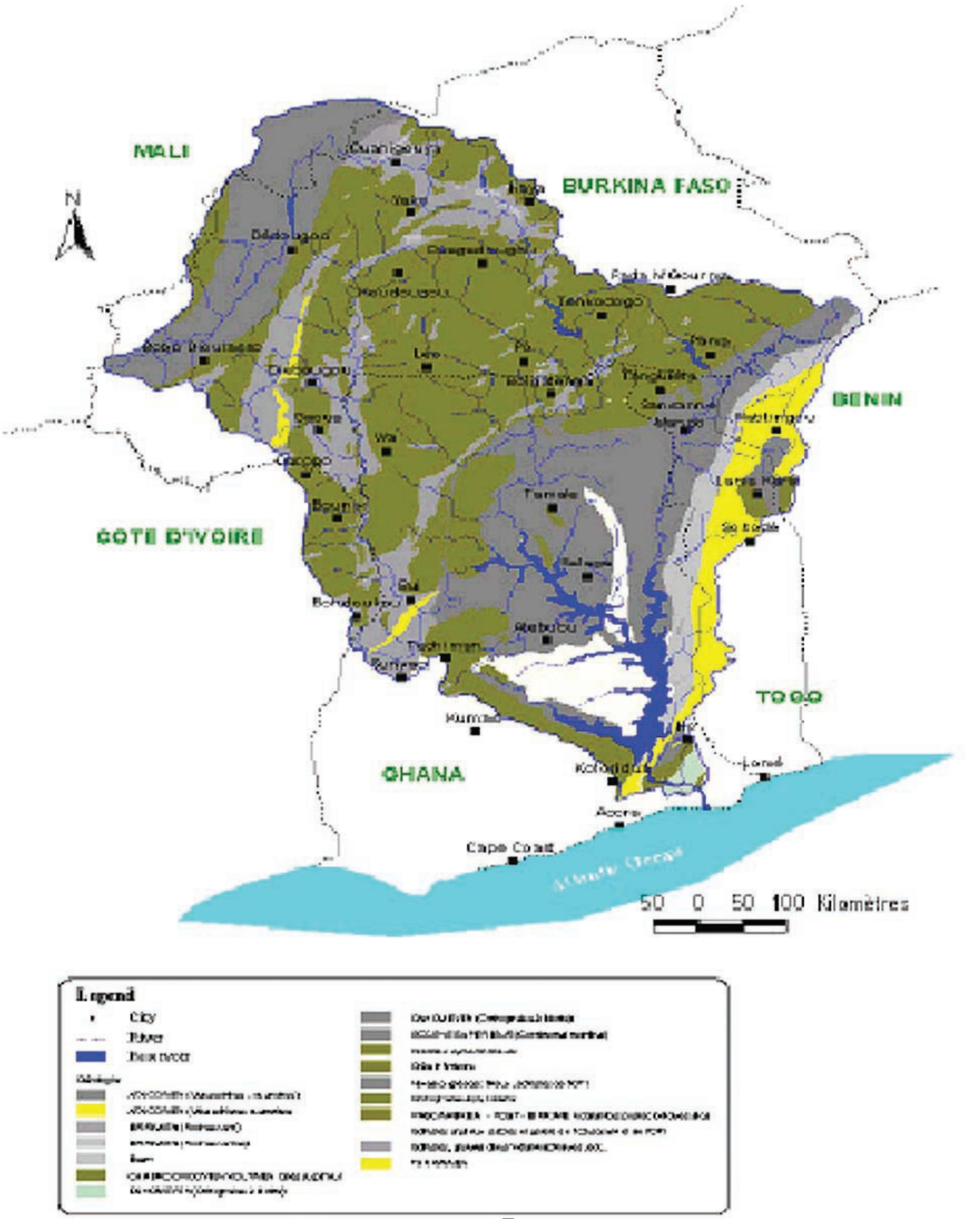

Figure 5: Geology of the Volta Basin

Soils

The soils of the Basin are derived from rocks of the mid Palaeozoic age or older, comprising mainly Siluro-Devonian sandstone and shales and some igneous and granitic material. They are characterized by an accumulation of organic matter in the surface horizon. Forest ochrosols are the most extensive and important of these soils. The rest, mainly in the wetter areas, are forest oxysol intergrades. The northern savanna contains much less organic matter and is lower in nutrients than the forest soils. The soils consist mainly of savanna ochrosols and groundwater laterites formed over granite and Voltaian shales. In the coastal savanna, soils are younger and closely related to the underlying rocks. They are mainly a mixture of savanna ochrosols, regosolic groundwater laterites, tropical black earths, sodium vleisols, tropical grey earths and acid gleisols, and are generally poor largely because of inadequate moisture (Table 7; Figure 6). The annual rainfall in the southern forest zone is between 1,000 and 2,000 mm.

Table 7: Major soil groups of the Volta Basin

Soil group	Predominant relief	Predominant texture	Erosion hazard
Savanna ochrosols	Upper and middle slopes gently undulating	Moderately heavy to light	Moderate sheet and gully erosions
Groundwater laterites	Near level to level lower slopes to valley bottoms	Light over concretion and ironpan	Severe to very severesheet erosion
Savanna ochrosols integrated	Gently undulating to level middle to lower slopes	Medium to light	Moderate to severe sheet erosion
Savanna lithosols	Summits with steep slopes	Meium to light	Severe gully erosion
Savanna gleisols (GLE)	Near-level to level lowlands	Moderately heavy to very heavy	Slight sheet erosion
Savanna GLE alluviosol integrades	Lowland terraces	Light to very light	Moderate to slight sheet erosion

Some of the factors that determine the soil fertility capability of the Volta basin soils are shown in Table 8. Soil acidity and steep slopes are the main factors that determine fertility capability in the basin accounting for 55% and 30% respectively.

Table 8: Soil fertility capability classification (FCC)

Fertility limitation type	Share of basin area (km^2)	Share of basin area (%)
Gley	51,996	12.5
Dry	0	0
Low CEC	21,531	5.2
Aluminium toxicity	9,705	2.3
Acid	227,171	54.8
High P-fixation	242	0.1
X-ray amorphous	0	0
Vertisol	23,263	5.6
Low K reserves	16,932	4.1
Basic reaction	0	0
Salinity	29	0
Natric	8,085	2
Cat clay	0	0
Shallow soils	70,455	17
Steep slopes (8-30%)	124,036	29.9
Very steep slopes (>30%)	20,406	4.9
Organic soils	0	0
Low moisture holding	91,064	22
Erosion prone soils	72,931	17.6
Not applicable	11,858	2.9

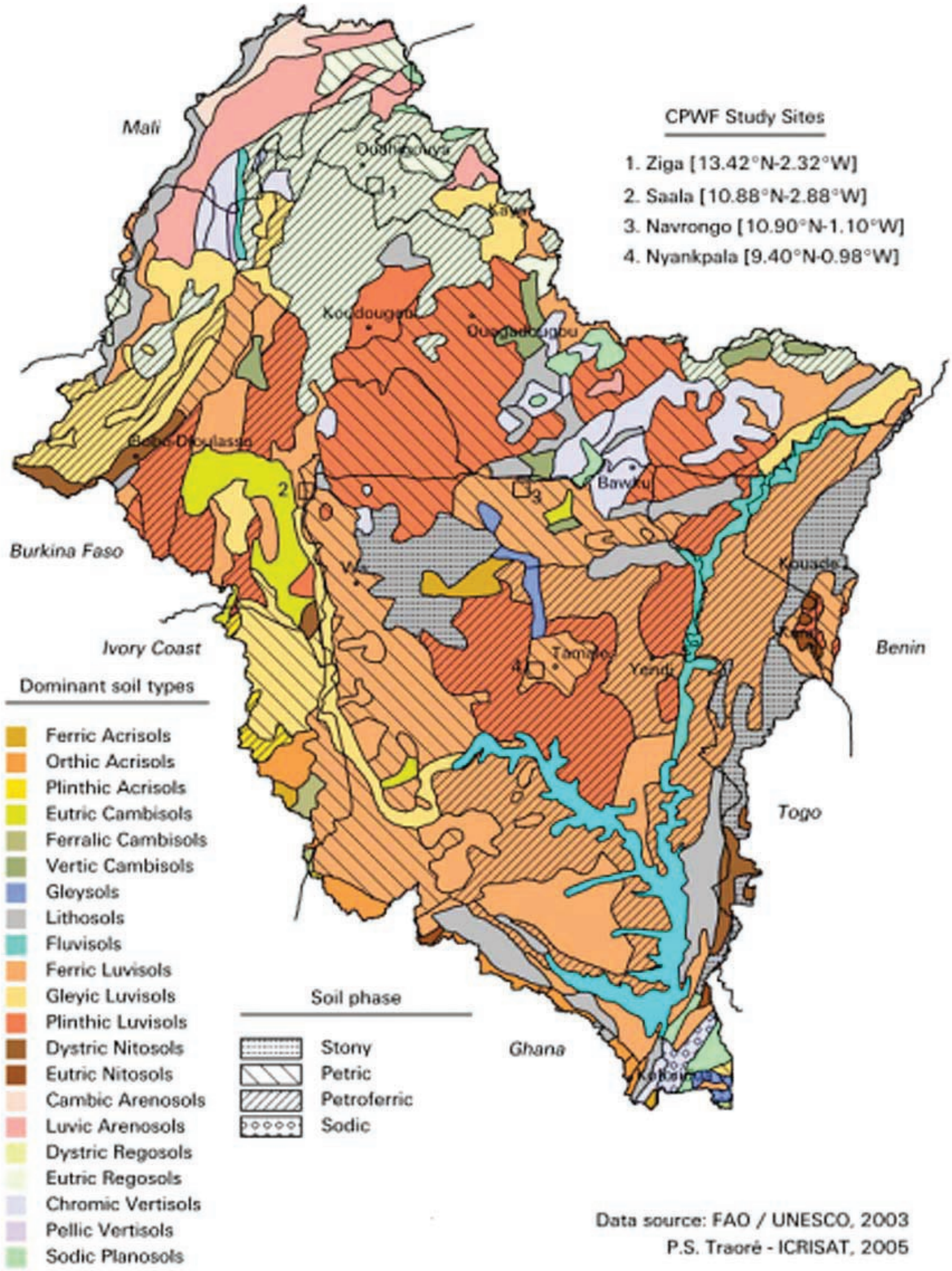

Figure 6: Soils of the Volta Basin

Drainage network

The Basin is drained by several major rivers: Black Volta, White Volta with Red Volta as its tributary, Oti River, and Lower Volta. The Oti River, with only about 18% of the total catchment area, contributes between 30 and 40% of the annual flow of the Volta River System. This is due to the steep topography and high rainfall in the Oti sub-basin. Oti River begins in the Atakora hills of Benin at an altitude of about 600 m A.S.L. and flows through Togo and Ghana. In Benin, Oti River is referred to as Pendjari River. Tributaries include the Koumongou, Kéran, Kara, Mô, Kpanlé, Wawa, Ménou, and Danyi.

The White Volta begins as the Nakanbé River in Burkina Faso. The Red Volta, referred to as Nazinon in Burkina Faso, and Sissili, are tributaries of the White Volta and they all have their source in Burkina Faso. The Sourou from Mali and the Mouhoun from Burkina Faso join in the latter country and flow downstream to Ghana as the Black Volta. In Burkina Faso, apart from the Mouhoun, all of the rivers, including the Nakanbé, Nazinon, and Sissili, dry up for approximately two months of the year. In Ghana, the Black Volta, the White Volta and the Oti join the main Volta at Volta Lake, which was created by the Akosombo Dam.

Water Resources in the Volta Basin

The Basin is mainly served by surface water resources (Volta river system) though groundwater resources are also available and have been exploited in all the basin countries. The estimation of direct recharge in the Volta River system is based on the assumption that recharge occurs when actual evapotranspiration and direct runoff are balanced by precipitation. This occurs when the soil is saturated to the field capacity, which is likely to occur when precipitation exceeds evapotranspiration. Analyses of rainfall data from various stations within the Volta River system indicate that the months in which precipitation exceeds evapotranspiration are usually June, July, August, and September. The annual recharge for the Volta River system ranges from 13.4 to 16.2% of the mean annual precipitation. On average, the mean annual recharge of the Volta River system is about 14.8% of the mean annual precipitation.

The mean annual flows of the Black Volta, White Volta, and Oti River are 8,300 x 10^6, 8,180 x 10^6, and 12,606 x 10^6 cubic meters respectively (MWH, 1997). The mean annual flow of the White Volta Basin is estimated to be about 300 m^3s^{-1}, where the percentage of flow from outside Ghana to the total flow is estimated to be 36.5%. The mean annual flow of the Black Volta at Bamboi is about 200 m^3s^{-1}, out of which about 42.6% originates from outside Ghana. Due to the regularization by the Kompienga Dam in Burkina Faso, the Oti River has a permanent flow with an annual average flow of 100-300 m^3s^{-1}, and can reach more than 500 m^3s^{-1}. Virtually all of the tributaries stop flowing during the dry season, and their average flows are only in the range of 5 m^3s^{-1}.

Availability of groundwater depends on the geological characteristics of the Basin, and mainly that of underground rocks. Rock porosity and permeability greatly influences the availability, occurrence and recharge of underground aquifers. Most rocks in the Volta Basin are impermeable, therefore, formation of aquifers, depends upon secondary porosity created as a result of fissuring or weathering. Weathering is a consequence of circulation of water through joints, fractures, and quartz veins that had formed earlier. Muscovite or hornblende can weather to approximately 30 m, whereas the Birimian formation can weather to a depth of approximately 73 m, thus giving rise to deep aquifers. Runoff coefficients are generally low meaning that direct recharge of aquifers from precipitation is less than 20% across the Basin. These figures do not give a good outlook for recharge of the groundwater resources.

The borehole yields are quite variable with a mean for all the sub-basins between 2.1 and 5.7 $m^3 h^{-1}$. These figures suggest that the groundwater yields in the Basin are low. Specific capacity is a measure of transmissivity of the aquifers. High specific capacity indicates a high coefficient of transmissivity and similarly, a low specific capacity indicates low transmissivity. The figures show that the region has low hydraulic transmissivity. The depth of aquifers is also variable in the Basin. There is no correlation between depths to aquifer and borehole yields (WARM, 1998). The results indicate that groundwater resources are not abundant in the Basin and face threats if not properly managed.

Land Use

Cultivation of crops and animal husbandry are the primary economic activities in the Volta Basin, making land a critical resource to the Basin's inhabitants. The resources currently meet these needs, but the growing population pressure that will require additional land, combined with the anthropogenic and climatic threats to land resources, suggest that this might not always be the case. Some lands are also preserved as natural habitats for flora and fauna, and are unavailable for use. However, illegal exploitation of the land resources has reduced their value.

Predominant land use of the White Volta is extensive land cultivation 3.2-9.6 km away from the village, with widespread grazing of large numbers of cattle and other livestock (up to 100 cattle km^{-2}) (FAO, 1991); and compound cropping (home gardening) around the house. Estimates of land use and land cover in 1989 showed that about 50% of the land in the northeast and northern parts of the Basin was in the compound and bush fallow cultivation cycle (IFAD, 1990). Farm sizes are usually about 1 ha. Grazing lands are poor and are those obtainable under natural conditions and annual bush burning. The major land use of the Black Volta is agriculture, with extensive bush fallow cultivation under food crops. The major food crops include yams, cassava, maize, sorghum, millet, groundnut, and beans. Animal grazing on free range is an important activity. Animal numbers are large in the northern and middle parts of the Basin in Ghana. Mining for gold in the Birimian rocks in the northern parts of the Basin in the 17th and 18th century has been reactivated as a growing small-scale surface mining activity. Urban land use is most intensive in Lawra, Wa, Bole, Damango, and Wench.

The Main Volta land use is short bush fallow cultivation along the immediate banks of the river, and less intensive bush fallow cultivation elsewhere. Animal grazing is common and the lake shores are extensively settled by fishing families. Charcoal burning involving the cutting of wood has become an extensive economic activity in the southern dry forest and transitional environments, for example, in various parts of the Afram sub-basin. The Afram plains and other areas in the south have been the focus of increasing settlement and agricultural development since the 1960s, having been generally thinly populated in the past as part of the empty "middle belt" (Dickson and Benneh, 1987). The forested and transitional areas are intensively farmed with cocoa, coffee, plantain, cocoyam, cassava, oil palm, and maize on small bush fallow plots. A large modern commercial farm at Ejara specializes in maize production. Some timber extraction takes place in these areas. Recent developments, particularly below the Akosombo Dam, include irrigated rice, sugar, and vegetable cultivation in the areas immediately adjoining the Volta River.

Human Population Densities in the Volta Basin

The basin's rural population, principally farmers, is highly variable in density (8–104 persons/km^2). Low densities can be observed in the central and northern areas of the basin, where conditions are more arid, and tsetse flies and related diseases are more prevalent. Archeological findings indicate, however, that the region was once more heavily populated. Periodic burning evidently occurred over extensive areas for perhaps more than a millennium, exposing the soil to excessive drying and erosion, rendering the area less attractive to cultivators.

Among other demographic characteristics, the size of the population, its growth rate, density, and rural/urban distribution have strong bearings on Basin-wide productivity and livelihood security outcomes. Demographic characteristics of countries in the Basin are given in Table 9. The countries with the largest population are Ghana (20 million), Côte d'Ivoire (16 million), and Burkina Faso and Mali (around 11 million each), while Benin (6 million) and Togo (5 million) have the lowest populations. The countries have one of the fastest growing populations in the world, although annual population growth rates vary considerably: Benin, Burkina Faso, and Togo between 2.4 and 2.6%; Côte d'Ivoire and Mali between 2.2 and 2.5%; and Ghana, the only country with a growth rate below 2%. Rural population growth rates are consistently lower than the national rate, whereas the urban rates are higher, which points to rapid urbanization and rapid increases in the urban areas as a result of rural urban migration.

Table 9: Share of Volta basin area occupied by different population density classes

Population Density (hab.km^2)	% of whole basin	% of Benin part	% of Burkina Faso part	% of Ghana part	% of Ivory C. part	% of Mali part	% of Togo part
<2	2.4	2.5	0.5	4.9	5.9	0.0	0.1
2-5	5.2	2.3	7.0	4.3	12.8	0.2	0.6
5-25	60.0	61.6	57.9	62.0	75.9	76.1	42.5
25-50	20.1	23.4	22.4	16.4	2.7	20.6	31.1
50-100	7.2	6.0	7.0	7.4	0.4	1.8	15.3
100-500	3.9	4.1	3.5	3.8	2.2	1.0	9.8
>500	1.2	0.1	1.8	1.1	0.2	0.2	0.6
All	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Population settlement in the Basin countries is largely rural, ranging between 56 and 83%. The countries with the lowest percentage of rural population, Côte d'Ivoire and Benin, have over 50% of their people living in the rural areas, whereas Ghana, Mali, and Togo have close to 66% of their people living in rural areas. The population density varies considerably, being highest in Ghana (87 km^{-2}), and Togo (86 km^{-2}), and lowest in Mali (9 km^{-2}) (Figure 7). Population density ranges between 40 and 60 km^{-2} for the other countries. There are intra-country variations in geographic distribution of population. For example, the population density of Ghana's Upper East Regions is 104 persons km^{-2}, while that of the Northern Region is only 26 persons km^2 (Figure 6). In Côte d' Ivoire, the population density varies from 8 persons km^2 in the north to 22 persons km^2 in the south. Further, valleys of the Black Volta where onchocerciasis, or river blindness, is prevalent are sparsely populated, because people fled to escape the parasitic disease.

Burkina Faso and Mali have the youngest population, that is, the largest percentage of the population falls between 0 and 14 years of age (47%), while Ghana has the lowest (43%). For all other countries, the 0-14 age group accounts for 44-46% of the total population. However, the major portion of the population falls into the working age group (15-64 years) for all countries, being highest for Côte d' Ivoire (55%), but varying between a narrow band of 50- 53% for the others. A relatively lower proportion of the population in the 0-14 age group and a higher proportion in working ages (15-67 years) in Côte d'Ivoire points to a relative slowdown in population growth rate, especially in rural areas, and high death rates, before entering the net age cohort. These effects are illustrated by the population pyramid of Ghana (Figure 8), which shows a high death rate, especially among young children. The population structure has major implications in terms of the dependency ratio, labor availability, future population growth, and altruism. Overall, high population growth rates and fast-growing populations, in all countries, remain a cause for concern in terms of food security, poverty alleviation, risk mitigation, disaster recovery, and environmental sustainability.

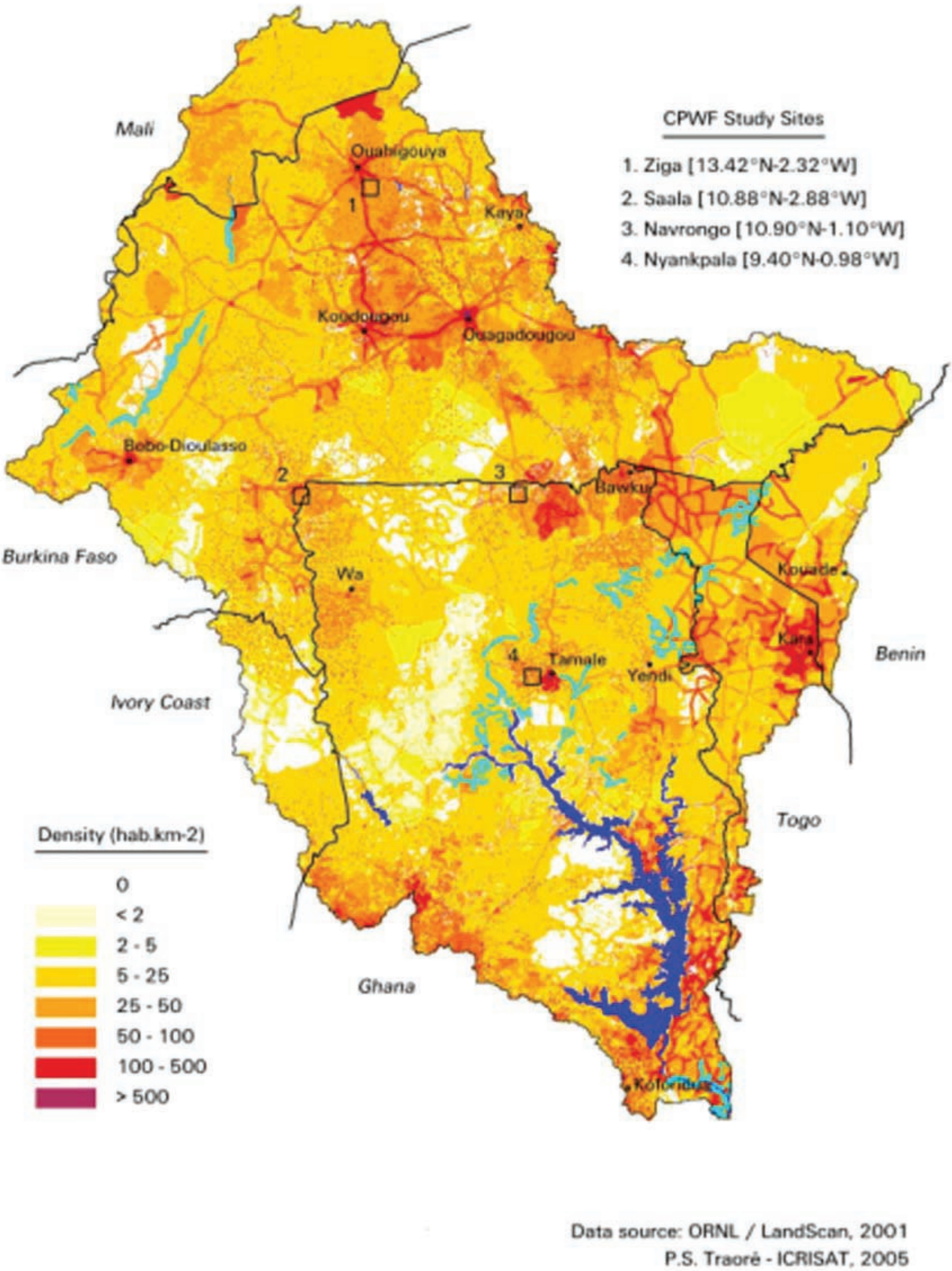

Figure 7: Human Population Densities in the Volta Basin

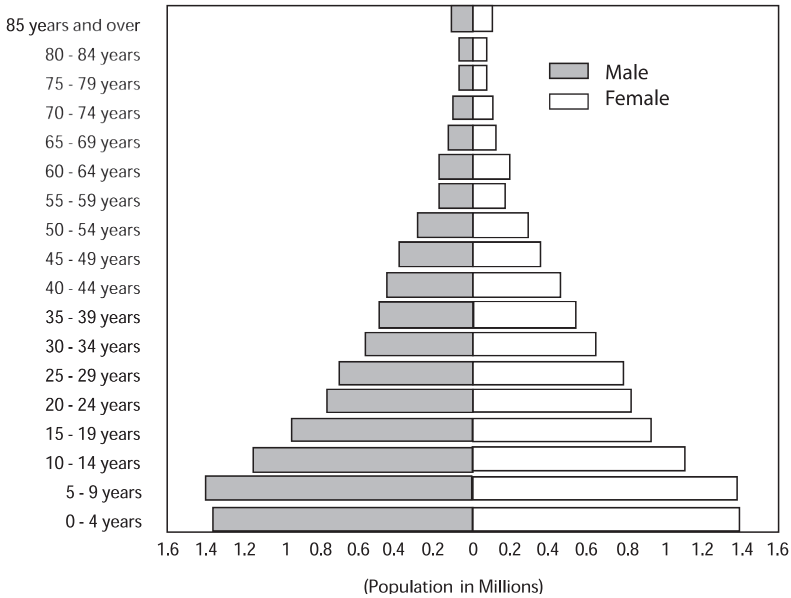

Figure 8: Age-Sex Structure of Ghana (2001 census)

Data from World Development Indicators (2003) show that during the 1990s, with the exception of Burkina Faso and Togo, rural population growth rates declined continuously in all countries of the Basin, although there is no reduction in population size, which continues to expand. It is estimated that over the next 40 years, Benin, Burkina Faso, and Mali will more than double their populations, while all other countries will experience an increase between 70 and 90% (Table 10). Even the country with the slowest-growing population, Ghana, will experience a 75% increase in its population. These trends will greatly increase pressure on aquatic ecosystems and other natural resources.

Table 10: Population projections (millions) for the Volta Basin countries

	2000	2010	2020	2030	2040	2045	Change 2000-45%
Benin	6.27	8.04	9.94	11.48	12.91	13.64	117.5
Burkina Faso	11.27	14.04	17.20	20.47	23.30	24.70	119.2
Cote d'Ivore	16.01	19.14	21.77	24.00	26.36	27.50	71.8
Ghana	19.30	22.76	26.62	29.81	32.84	34.28	77.6
Mali	10.84	13.42	16.43	19.14	21.42	22.64	108.9
Togo	4.53	5.53	6.57	7.47	8.30	8.70	92.1

*Data source: WDI (2003), except *(HDR,2000)*

Conclusion

The Volta basin is located in the Sub-humid to Semi-arid Savanna zone of West Africa covering over 400,000 km^{-2}. Climatic conditions in the region are dominated by the movement of the Inter Tropical Convergence Zone (ITCZ) which is the region where the hot, dry and dust harmattan air mass from the Sahara in the North meets the cool, moist monsoon air from the South Atlantic. Movement patterns of the ITCZ on north-south swats control the amount and duration of rainfall received in different parts of the Basin. The basin lies mainly in Ghana (40%) and Burkina Faso (42%) with minor parts in Togo, Côte d' Ivoire, Mali and Benin. Ghana occupies the downstream part of the basin. A dominating feature of the basin is Lake Volta, which is the largest man-made in the world in terms of surface area (4% of total area of Ghana).

The Basin in general has a low relief with altitudes varying between 1 and 920 m. a.s.l The average mean altitude of the Basin is approximately 257 m. a.s.l, with more than half the Basin in the range of 200-300 m. a.s.l. The global slope index is between 25 and 50 cm/km^{-1}. The Volta sub-basins comprise the White, the Black Volta, the Daka and the Oti basins. The soils of the Basin are derived from rocks of the mid Palaeozoic age or older, and are characterized by an accumulation of organic matter in the surface horizon. Forest ochrosols are the most extensive and important of these soils. Soils to the northern Savanna zone have low organic matter on the surface horizons and consist mainly of savanna ochrosols and groundwater laterites formed over granite and Voltaian shales.

Savanna vegetation is the most dominant in the Volta Basin. As one moves northwards the vegetation changes from grasslands to dry shrublands as the conditions get more arid. On moving South, vegetation changes from savanna to the intensive croplands and moist forests as conditions get moist.

Cultivation of crops and animal husbandry are the primary economic activities in the Volta Basin. From northern Ghana where both economic activities are carried out, crop cultivation intensifies as one moves south while pastoralism intensifies northward. The major food crops include yams, cassava, maize, sorghum, millet, groundnut, and beans. Animal grazing on the free range is an important activity. Animal numbers are large in the northern and middle parts of the Basin.

The basin's population, principally farmers, is highly variable in density (8–104 $persons/km^{-2}$). Low densities can be observed in the central and northern areas of the basin, where conditions are more arid. Among other demographic characteristics, the size of the population, its growth rate, density, and rural/urban distribution have strong bearings on Basin-wide productivity and livelihood security outcomes. On average, majority of the population in all the Volta Basin countries is largely rural, ranging between 56 and 83%. Burkina Faso and Mali have the youngest population, with the largest percentage of the population falling between 0 and 14 years of age (47%), while Ghana has the lowest (43%). The population structure has major implications in terms of the dependency ratio, labor availability, future population growth, and altruism. Overall, high population growth rates in the Volta Basin and fast-growing populations in all countries remain a cause for concern in terms of food security, poverty alleviation, and environmental sustainability.

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Chapter 2

Soil Resources of Ghana

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Abstract

Ghana is endowed with a number of soil resources developed over various geological formations within the agro-ecological zones. The soil resources are essential for human life in the provision of food, shelter and fuel and serve as the basic support of many life processes. Agricultural production which is the main stay of the country's economy, depends on the quality of the soil resources. Soil research activities began in Ghana in 1945 when the Soil Research Institute was established. Systematic soil inventorization was undertaken within the 35 river basins covering the whole country. The basins were surveyed at detailed reconnaissance level and soil and soil suitability maps were produced at a scale of 1:250,000. Numerous detailed and semi-detailed soil surveys have been carried out on lands earmarked for projects. A soil classification system suitable for classifying soils of Ghana was developed and used. The major soil resources of the country are presented. They are described and evaluated. The soils are also classified into the FAO's WRB and the USDA's Soil Taxanomy. Examples of their local names are also presented. Brief presentation of the fertility status of the soils as well as natural and anthropogenic causes of fertility decline and their impact on agricultural production are highlighted.

Key words: *Soil types, soil fertility, Ghana*

Résumé

Le Ghana est doté de ressources en sol développeés à travers des formations géologiques dans différentes zones agro-écologiques. Les ressources en sol sont essentielles pour la vie des hommes dans la provision en nourriture, eau et énergie; et servant aussi de support de base pour plusieurs processus de la vie. La production agricole qui constitue la principale ressource économique du pays dépend de la qualité des ressources en sol. Les activités de recherche en sol avaient commencé en 1945 lorsque l'institue de recherche en sol avait été crée. Un inventaire systématique des sols était entrepris sur 35 bassins couvrant l'ensemble du pays. Une enquête détaillée de reconnaissance des sols des bassins avait permis la mise en place d'une carte de sol a l'échelle 1/250.000. Plusieurs autres enquêtes détaillées et semi-detaillées avaient été entreprises sur des terres pré-sélectionnées pour les projets. Un système de classification des sols adapté aux sols du Ghana était développé et utilisé.

Les ressources majeures en sol du pays étaient présentées. Elles étaient décrites et évaluées. Les sols étaient aussi classifiés selon la taxonomie de FAO WRB et USDA. Des exemples pour leurs noms locaux étaient aussi présentés. Une brève présentation du statut de la fertilité des sols de même que les causes enthropogéniques de leur dégradation ainsi que leur impact sur la production agricole ont été énumérés.

Mots clés: *Types de sols, fertilité des sols, Ghana*

Introduction

The soil is an essential support for human life not only in relation to direct food production but also for the support and provision of shelter and fuel. The soil is the basic support of many life processes. It is the major constituent of the environment and regulates a number of bio-physical and bio-chemical processes of environmental concern. Agriculture which is the mainstay of the economies of many developing countries like Ghana, contributing substantially to their Gross Domestic Product (GDP), depends mainly on the types of soil and how well they are managed. It is towards these realization that the Soil Research Institute (SRI) was established to investigate into the soil resources of the country and make appropriate scientific recommendations for high and sustainable agricultural productivity. Ghana is endowed with a variety of soils that can be used for the production of different crops, and if well managed and conserved to sustain the present and future production.

The soil research activities in Ghana began in 1945 at the then West Africa Cocoa Research Institute (WACRI) now Cocoa Research Institute of Ghana (CRIG) at Tafo, Eastern Region when soil investigation unit was set up. The unit since then has developed into the present day SRI at Kwadaso-Kumasi. The soil research activities in the country are being undertaken presently under soil inventorisation, soil fertility enhancement and soil conservation and erosion control programmes.

Soil Inventorization

The soil inventorization activities involve soil mapping, soil identification, soil description, soil classification and land evaluation. The whole country has been demarcated into 35 Soil Survey Regions based mostly on river basins of the country. These regions have been soil surveyed systematically.

In course of the inventorization exercise, it became necessary to establish a soil classification system suitable for classifying soils of Ghana. The system developed was multicategorical one with levels of generalization from Soil Order through Suborder, Soil Group Family, Great Soil Group, Great Soil Subgroup to soil series (Brammer, 1962).

Based on the vegetation, geology and slope characteristics the soil resources of the regions have been mapped, described and evaluated for their uses. The units of mapping of the soils were soil associations, soil complexes and soil consociations. The soil associations consists of soil series that occur regularly within a landscape of regularly occurring topography that can be mapped together while soil complexes consists of group of diverse soil series occurring mostly on rugged surfaces where the units occur in an irregular pattern so intricately mixed that the components units cannot be delineated separately at the mapping scale used. Soil consociation is made up of similar soil series that occur extensively over the terrain and can be delineated separately. Each mapping unit consists of soil series which are defined as soil units with similar profile morphological characteristics derived from similar conditions of climate, vegetation, relief and drainage. The component soil series of the mapping units are described in detail and sampled for physico-chemical laboratory studies.

The inventorization activities were carried out at detailed reconnaissance level and soil and soil suitability maps at a scale of 1:250,000 and accompanying soil report have been published. Numerous detailed and semi-detailed studies at various scales have been conducted on lands for medium and large scale agricultural ventures. These include irrigation, arable and plantation projects.

Soil Resources

The major characteristics of the soils resources of the country that affect their uses are acidity, gravel, stone and ironpan contents within and on the soil surface, texture, structure, drainage conditions, fertility status, their positions on the landscape and susceptibility to erosion hazards (Adu, 1969, 1992; Asiamah, 1987).

The major soil resources of Ghana according to Ghana Interim Soil Classification System (Brammer, 1962) are:

1. **Savanna Ochrosols**

   These soils are red to reddish brown, well to moderately well drained and medium to light textured that occur usually on summits to middle slopes. Most of them have illuvial clay accumulation within the subsoils. Soil reaction ranges from near neutral to moderately acid (pH 6.5 – 5.5) within the topsoils with slight increases with depth. Soil depths vary from shallow to very shallow (0.45 cm), through moderately shallow to moderately deep (45 – 90 cm) to deep to very deep (90 – 150 cm^+). These soils occur extensively within the savanna and transition zones of the country and together cover nearly 57,400 km^2. They are the most important agricultural soils within the savanna regions for the production of a number of climatically suited crops like yams, cassava, cotton, tobacco, cereals, legumes vegetables and are best for pasture developments. They are classified into Luvisols, Lixisols, Acrisols, Nitisols and Cambisols. Examples of savanna ochrosols are Damongo, Nyankpala, Ejura sand Oyarifa series.

2. **Groundwater Laterites**

   These are the most extensive soils of the savanna regions covering nearly 27,000 km^2. They form sheets of shallow soils over hard ironpan that dominates the centre of the Volta basin. They occur on nearly level lands developed over shales and mudstones. The soils are shallow to moderately deep, pale coloured, imperfectly and poorly drained sandy loams with near neutral to moderately acid (pH 5.6 – 6.6) in reaction within the topsoils. They become waterlogged during the wet seasons and dry out completely in the dry seasons. Characteristically present in these soils at various depths are well developed plinthites which under adverse dry climatic conditions harden irreversibly to ironpans. Their nutrient contents are very low. They are used for the production of rice, sorghum, millet, beans, Groundnut and pasture. They fall within the units of Plinthosol, Lixisols, Alisols, Gleysols and, Planosols and Cambisols. Examples of groundwater laterites are Kpelesawgu, Changnalili, Bianya and Gulo series.

3. **Savanna Lithosols**

These are very shallow, rocky and concretionary soils among rock outcrops on steep slopes. They are not suitable for arable cropping and must be devoted to forestry and wildlife purposes. They cover nearly 11,400 km^2 within both the Interior and Coastal Savannas. They are classified as Leptosols and Regosols.

Examples are Gbache, Male, Chuchuliga and Bare series.

4. **Savanna Gleisols**

These soils are very deep, medium to heavy textured, grey to dark brown, mottled, non-gravelly, imperfectly to poorly drained. They are developed over colluvio-alluvial deposits in large depressions and valley bottoms showing pronounced hydromorphic properties. The soils cover approximately 16,000 km^2 and can be used for the cultivation of rice, sugarcane and vegetables. They are classified as Gleysols, Planosols, Livisols, Arenosols and Cambisols. These soils under effective fertilization, irrigation and drainage management can be used to produce rice, sugarcane, legumes and vegetables and examples are Amo and Dagare series.

5. **Tropical Black and Brown Earths**

These are dark-coloured heavy clay soils developed over basic rocks. In the dry seasons, they shrink in volume and crack wide and deep and become hard. In the wet season they become plastic and sticky swelling up to 40% in volume. Clay mineralogy is mostly montmorillonite. Gilgai microrelief is common on these soils. Local farmers have avoided cultivating the soils because of their heavy textures and difficult moisture relationships. With heavy machinery, skill management and effective drainage and irrigation facilities, however, the soils can be used to produce rice, sugarcane, cotton, legumes and vegetables. A total of 2,127 km^2 of these soils have been mapped especially within the Coastal Savanna Zone. They are classified as Vertisols and Vertic Cambisols and examples are Akuse, Prampram, Tefle, Bumbi and Lupu series

6. **Tropical Grey Earths and Regosolic Groundwater laterites**

These soils developed over acidic gneiss and schist within the Coastal Savanna Zone. They are grey in colour, moderately deep to deep and have well developed sodium impregnated claypans. The topsoils are light in textures but heavy within the subsoils. These soils are low in organic matter and plant nutrients and are used to produce, vegetables, maize and cattle rearing. They cover approximately 3,670 km^2. The soils are classified as Solonetz, Planosol and Lixisols.

The Regosolic Groundwater Laterites are pale-coloured sands overlying mottled, gravelly sandy clays underlain by weathered acid gneiss or granite. The soils cover about 150,087 ha within the coastal savanna zone. Under good management the soils can be used for millet, groundnut, guinea corn, maize and vegetables and citronella grass and examples are Agawtaw, Ziwai, Doyum and Simpa series.

7. Sodium Vleisols

These sodium enriched soils are found mostly along lagoons and creeks in the Lower Volta Plains. The soils are black to dark grey, clay, sticky and plastic when wet but hard when dry with the soil surface encrusted with salt crystals. The soils that cover approximately 900 km^2 are not suited for agriculture but used for livestock rearing. They have been classified as Solonetzs and Solonchaks (Brammer, 1962, 1967, Asiamah, 1999, 2001) and examples are Muni, Truku, Songaw and Oyibi series.

8. Forest Oxysols

These are the upland soils of the extreme south-western end of the country where annual rainfall is around 2000 mm. These soils are deeply weathered, heavily leached of nutrients, highly acidic in reaction, reddish brown to yellow in colour, well to moderately well drained and cover an area of approximately 6500 km^2. They are used to produce coconut, oil palm, rubber, bananas and citrus. The soils are classified as Ferralsols and Acrisols and examples are Tikobo, Nuba, Boi, Ankasa series.

9. Forest Ochrosols

These are the most extensive upland soils of the forest zones. The soils are dark brown to red, well to moderately well drained on summits to middle slopes. The soils are moderately acid to acid (pH 5.6 – 6.5) within the topsoils but acidity generally increases with depth. These soils have a marked concentration of organic matter and nutrients in the topsoils with leached lower horizons. Most of them have concentration of illuvial clay within the subsoils.

Three groups of Forest Ochrosols are recognized in Ghana. The first group consists of soils of moderately deep, well to excessively drained and gravelly with medium to moderately heavy textures overlying parent rocks. They occur on undulating to sloping topography and are not suitable for mechanised agriculture. They are used for hand cultivation of tree cash crops like cocoa, coffee, oil palm, citrus and other food crops.

The third group consists of soils limited in depth to rocks or ironpan, moderately well drained, gravelly, medium to light textured. They are not suitable for agricultural production but are devoted to forestry and wildlife purposes.

The Forest Ochrosols are classified mostly as Luvisols, Lixisols, Acrisols, Alisols, Cambisols and Nitisols. The Forest Ochrosols together cover approximately 31,500 km^2 and examples include Kumasi, Bediesi, Juaso series

10. Forest Lithosols

These are very shallow, rocky and concretionary soils on steep to very steep hilly and mountainous sides. They are well to excessively drained brown to red in colour full of concretions and among rock and ironpan outcrops. The soils cover a total of about 5500 km^2 and are unsuitable for agriculture but left for forestry, watershed and wildlife protection purposes. They are classified as Leptosols and Regosols.

11. Forest Gleisols

These are lowland soils of large depressions and valleys within the forest zones. They are deep to very deep, dark brown to grey, imperfectly to very poorly drained, medium to heavy clays developed river colluvio-alluvial sediments. They are cultivated to rice, sugarcane and vegetables. They cover a total of approximately 4900 km^2. They are mostly Gleysols, Planosols, Arenosols, and Cambisols.

12. Forest Gleisols – Alluviosols

These soils are found along the levees and flood basins of the major rivers within the forest zones. They are very deep, moderately to imperfectly drained, sandy loams, loose sands and clays. The well to moderately well drained soils of the levees are used to produce arable food crops while the heavy Gleisols of the basin can be used to produce rice, sugarcane and vegetables. They are Arenosols, Cambisols and Vertisols. They are limited in extent and cover approximately 700 km^2.

13. Regosols

These are the soils of the recent marine deposited sands along the beaches. The soils have shallow dark grey, humous stained sandy topsoils with coarse, loose sands of several meters in depth. The soils are saline and mottled with undecomposed marine shells. Only coconuts do well on these sandy soils. They cover some 800 km^2 along the beaches of the Coastlines. They are mostly Arenosols and Cambisols.

14. Regosolic Groundwater Podzols

These are soils of silted old lagoon sites found in limited extent in the high rainfall zone. The soils are very acidic, loose white sands with only shallow humous stained topsoils. They carry only short grasses and are not used for agriculture.

They become waterlogged most of the year. These soils are classified as Podzols, Albic Arenosols. Some examples of these soils are Esiama and Atuabo series.

The major Soils of Ghana under FAO World Reference Base (WRB) for Soil Resources (FAO 1998) and Soil Taxonomy (NRCS, 1999)

1. **Plinthosols** *(Plinthustalfs, Plinthaqualfs, Plinthaquox)*

   These are soils with plinthic materials or petroplinthite (hard ironpan) occurring within 50 cm from the soil surface or soils with plinthic horizon starting within 100 cm from the soil surface when underlying an albic horizon or a horizon with stagnic properties. These soils occur in all the agro-ecological zones. They are poor for agricultural production because of their low contents of humus and phosphorus and are impenetrable to air water and roots. They induce soil erosion. Plinthite is formed from accumulation of oxides of iron in the clayey subsoils and when subjected to repeated wetting and drying seasonal conditions it changes irreversibly to petroplinthite (ironpan) to degrade the soil permanently. These materials occur in soils covering over 54 per cent of the total land area of Ghana (Asiamah, 2000).

   Examples: Wenchi, Chagnalili, Kpelesawgu series.

2. **Ferralsols** (*Eutrudox, Kandiudox, Acrudox*)

   The soils occur in south western parts of the country within the High Rainfall Forest zone where annual rainfall is in the neighbourhood of 2000 mm. They are deeply weathered and heavily leached of bases and are therefore strongly acid in reaction. The soils are suited for the production of coconut, rubber, citrus, oil palm and banana.

   Examples: Tibobo, Nuba Boi, Ankasa series.

3. **Arenosols** (*Quartzipsamment, Ustipsamment, Udipsamment*)

   These are sandy soils occurring along the beach or along immediate banks of major rivers of the country. They are defined as soils with texture which is loamy sand or coarser to a depth of at least 100 cm from the soil surface or to a plinthite, petroplinthite or salic horizon between 50 and 100 cm from the soil surface and having less than 35 per cent by volume rock fragments or other coarse fragments within 100 cm from the soil surface. They are used for the cultivation of coconut along the beach and oil palm in the forest zones. Shallots are intensively cultivated on these sandy soils around Keta.

   Examples: Chichiwere, Keta

4. **Lixisols** (*Paleustalfs*)

   They are well to moderately well drained upland soils having argic horizon within the subsoil and CEC of less than 24Cmol kg^{-1} clay and a base saturation of more than 50 percent in the major parts between 25 and 100 cm. they are moderately leached soils that occur mostly in the savanna regions and used for the cultivation of most savanna crops. They are however low in natural fertility and susceptible to accelerated erosion.

Examples are Damongo, Ejura, Puga series

5. **Luvisols** (*Paleustalfs*)

These soils occur in both the forest and savanna zones. They have high CEC of equal to or more than 24 cmol kg^{-1} clay and base saturation of more than 50% in all parts of the subsoils. They have well developed argic horizon. They are suitable for the production of a number of plantation and food crops.

Examples are Nankesi, Mankoadzi and Dorimon series

6. **Acrisols** (*Paleustults*)

The soils have well developed argic horizon with low CEC of less than 24 Cmol kg^{-1} clay and low base saturation of less than 50% per cent in the major parts of the subsoils between 25 and 100 cm. They are acidic in reaction and occur extensively in the forest zones. They are suitable for the production of both plantation and food crops.

Examples are Kumasi, Manfe, and Asikuma series

7. **Alisols** (*Paleustults*)

They are well to moderately well drained upland soils with well developed argic subsoil horizon. They have high cation exchange capacity and low base saturation. They are suitable for both tree and arable crops.

Examples are Zongo, Yanahin series.

8. **Fluvisols** (*Fluvents*)

They are soils formed over alluvial deposits of river and streams valleys and flanks. They are mostly poorly to imperfectly drained liable to flooding and waterlogging. They have fluvic soil materials starting within 25 cm from the soil surface and continuing to a depth of at least 50 cm from the soil surface. They can be used for the production of rice and vegetables. In forest zones where water is always available soils are being used for tree crop production including cocoa and oil palm.

Examples: Volta, Ofin, Oda, Kunkwa series.

9. **Solonetz** (*Halaquepts*)

These are sodium salt affected soils with a natric horizon within 100 cm from the soil surface. They occur in flats and depressional bottom mostly within the coastal savanna zone. They are not suited for crop production but are used for lifestock licking and harvested commercially for table salt.

Examples: Oyibi, Agawtaw and Songaw series.

10. **Solonchaks** *(Natraqualfs)*

They are salt-affected soils with salic horizon starting within 50 cm from the soil surface. They occur within the coastal savanna zone along creeks and depressional bottom inundated with saline water. They are not utilized for agricultural production but have mangrove vegetation.

Examples are Truku, Muni series

11. Leptosols (*Ustorthent, Udorthent*)

They are shallow soils to solid rock or are highly concretionary and gravelly soils. They are limited in depth by continuous hard rock within 25 cm from the soil surface or containing less than 10 per cent by weight fine earth to a depth of 75 cm or more from the soil surface. They occur extensively in all agro-ecological zones especially on eroded surfaces and on steep slopes of mountains and inselbergs. They are not used for agriculture but left for natural regeneration.

Examples are Nyanao, Kobeda, Korle series

12. Nitisols (*Kandiustalfs, Paleustalfs*)

These are upland well drained soils with evenly clay distribution within the subsoils, shiny ped faces, gradual boundaries between horizons and nutty structure. They have nitic horizon starting within 100 cm from the soil surface. The soils are of limited occurrence within the savanna and forest zones. They are excellent for the production of both arable and tree crops.

Examples are Ansum, Atukrom and Atewa series

13. Vertisols (*Usterts*)

They are heavy clay soils that swell when wet and shrink when dry. They are of montmorritic clay and move within the volume creating slickensides and with surface gilgai microrelief. They are excellent soils for irrigated rice, sugarcane and vegetable production. They occur extensively in coastal savanna zone and in some depression and valleys in the Interior savanna zone.

Examples are Akuse, Prampram, Kupu and Tefle series

14. Cambisols (*Ustepts*)

These are moderately developed soils on colluvial and alluvial deposits on middle or lower slopes. The subsoil structures are not well developed. They occur as footslope soils of mountainuous area and river terraces throughout the ecological zone. They are however used for the production of variety of crops.

Examples: Murugu, Nta and Amo series.

15. Regosols (*Orthents*)

These are loose undeveloped soils with no diagnostic horizons. They occur in the country as recent colluvial deposits and as alluvial and marine sand deposits.

Examples are Jamasi, Fredericksburg series.

16. **Gleysols** (*Aquents*)

They are hydromorphic soils occurring in flat depressional bottoms along rivers and streams subject to flooding and waterlogging. They are undeveloped soils with gleyic properties within 50 cm from the soil surface. They occur throughout the agroecological zone and may be used for the production of rice and vegetables under good water management and fertilization.

Examples are Pale, Yaroyili, Temang series

17. **Planosols** (*Epiaquods*)

These are hydromorphic soils with light textured topsoil overlying heavy textured subsoil. They have albic horizon and occur especially in the savanna zones where there is stagnation of water. They are define as soils with an eluvial horizon, the lower boundary of which is marked within 100 cm from the soil surface, by an abrupt textural change associated with stagnic properties above that boundary. With effective water management they can be used for the production of shallow-rooted annual crops.

Examples are Atuabo, Esiama, Lima series.

Soil Fertility Status of Ghanaian Soils

The productivity of a soil is linked directly with its fertility status. The effectiveness of the soil in producing adequate quantities of food and fiber depends primarily on its fertility status which is defined as the ability of the soil to support crop growth by ensuring adequate and balanced supply of essential nutrients.

Most Ghanaian soils are old and have been leached for a long time and have lost the greater part of the tropical nutrient reserves. Under the humid and tropical climatic conditions in which the parent rocks have been strongly weathered, the predominant clay minerals in the soils are kaolinitic which has low cation exchange capacity. The level of organic matter in the soils is relatively low, particularly in savanna soils. Organic mater is very closely associated with the soils nutrient levels, because it has high cation exchange capacity and that the whole of the soil's nitrogen, phosphorus and micronutrient reserves are associated with it. Thus the fertility reserves of the soil are very largely associated with its organic matter content (Nye and Stephens,1962).

Presently there is a wide variation in soil fertility levels in the country due to differences in soil parent materials, environmental conditions and management practices. Soil infertility has been the fundamental biological root cause for declining per capita food production in the tropics (Smaling *et al*, 1997; Sanchez and Palm, 1996). Food production in Ghana will continue to decrease unless soil fertility decline is effectively addressed. The problem of soil fertility decline is a consequence of socio-economic constraint and policy distortions.

Since 1949 soil fertility enhancement research activities have been undertaken in the agricultural stations located within the agro-ecological zones which have resulted in recommendations of the types and rates of fertilizers and effective management practices to increase fertility levels of the soils to boost agricultural production for various climatically suited arable and plantation crops. The importance of soil microorganisms in improving soil fertility are numerous and include:

i. The formation of various organic acids that results in greater solubility of soil nutrients particularly carbonates and phosphates
ii. Synthesis of a variety of organic substances form inorganic compounds
iii. Oxidation and otherwise transformation into readily available forms various minerals introduced to the soil as ammonium salts or sulphur.
iv. Decomposition of plant and animal residues added to the soil and liberation of N and minerals necessary for plant growth.
v. Entering into various associations with plants that are highly important to plant growth for example symbiotic nitrogen fixation.

Most studies on soil microorganism in Ghana have centered on the nodule bacteria that form symbiotic association with legumes as a means of incorporating the full potential of N_2 fixing legumes into farming systems.

Some leguminous plants that have been identified as efficient in fixing nitrogen in Ghanaian soils include:

a. Crotolaria ratusa
b. Pueraria phaseoloides
c. Stylosanthes guianensis
d. Cajanus cajan
e. Vigna ungniculata
f. Arachis hypogaea L.
g. Gliricidia sepium
h. Leucaena diversifolia
i. Sesbania calothyrsus.

Important contributions relate to studies on the diversity of the bacteria (Fening and Danco 2001; 2002; Fening *et al*, 2001, 2002, 2003). The presence or absence of a homologous Rhizobium with host legume in a soil is the first prerequisite to nodulation and biological nitrogen fixation (BNF) by legumes. These studies have established that cowpea *Bradurhizobium* population in Ghanaian soils are in the range of 6 to 31,000 cells per gram of soil, and their diversity is high reaching 80%. The estimated values of effectiveness for fixing nitrogen ranged from 23.5 to 118%. Inoculation of cowpea with these strains resulted in an estimated 56% N fixation by the ^{15}N.

A number of natural and anthropogenic factors have been found to cause low soil fertility in the country. These include poor parent materials, high rates of mineralization and leaching, soil erosion, deforestation, overgrazing, tillage practices, nutrient mining, plinthite formation etc.

Natural causes of soil fertility decline

1. Leaching

High rates of mineralization and leaching under the tropical environment are the main causes of soil fertility decline. Mineralization is rapid under our tropical climate and plant nutrients are easily leached from the exploitable volume when the soils are subjected to intensive and prolonged percolation by rain water. In such situations nutrients are either removed from the soil laterally or are deposited deep within the soil out of reach of crops. Such leached soils are devoid of bases and the exchange complex is filled with hydrogen and aluminium ions rendering the soils acidic as occurs in the high rainfall forest zone.

2. Plinthite formation

Plinthite and its hardened form, petroplinthite (ironpan) are being formed extensively in the soils of Ghana. Plinthite is of high iron and low humus content devoid of bases and most essential elements and are therefore poor for crop growth. The high iron content causes phosphorus to be fixed and made unavailable to crops. Petroplinthite is impenetrable to water and air and restricts root movement. It induces erosion of soil materials above it. Asiamah and Dedzoe (1999) and Asiamah (2000) found that 54 per cent of lands in Ghana have plinthite developed in them and are being hardened to make them barren.

3. Soil erosion

Soil erosion is the most widespread cause of soil infertility in the country. It causes extensive soil loss throughout the agro-ecological zones; for example, Asiamah (1987) recorded that 35,172 km^2 are affected by slight to moderate sheet erosion, 27,306 km^2 by moderate to severe sheet erosion and gully erosion and 33,494 km^2 by moderate to very severe sheet and gully erosion in the Interior Savanna zone. In the High Rainforest zone which is even under the protection of thick forest vegetation, 2,745 km^2 are affected by slight to moderate sheet erosion, 16, 913 km^2 by severe sheet and gully erosion and 3,675 km^2 by moderate to very severe sheet and gully erosion.

Practices that enhance soil erosion include improper agricultural practices, improper land clearing and tillage practices, improper soil and crop management practices, deforestation, overgrazing and annual bush burning. The high erodibility of the soils of Ghana and high erosivity of the rainfall are important factors that speed up erosion of the soils when the vegetative covers are removed. The topsoils lost through erosion are usually the most fertile parts of the soil containing most plant nutrients, organic matter and any fertilizers that have been applied. Bojö (1996) estimated that the gross annual economic loss due to soil erosion is around 2-5% of agricultural gross domestic product (AGDO). Using the replacement cost approach (RCA), Convery and Tutu (1990) assessed the cost of annual production lost through erosion and nutrient depletion in Ghana to be US$166.4 million which is about 5% of AGDP.

4. **Low inherent fertility parent materials**

   Most soils in the country are inherently poor in natural fertility due to poor parent materials. These soils are formed from products of rocks low in nutrient elements. The clay mineralogy is mostly kaolinitic (Low Activity clays) and soils are naturally devoid of plant nutrients and have low cation exchange capacity. If such soils are continuously used without adequate external fertilizer inputs, they lose their fertility fast and become barren causing reduction in crop yields.

Anthropogenic causes of soil fertility decline

1. **Deforestation and overgrazing**

   Deforestation of vegetative resources is occurring at an alarming significantly to soil fertility loss. Farming, animal rearing, timber harvesting, charcoal production, fuel harvesting, bush burning, road construction, urbanization etc have resulted in significant over exploitation of natural vegetative covers. In Ghana, forest covers are disappearing at an alarming rate. The total forest area in 1977 was 74,400 km^2 and this has been reduced in 10 years to merely 18,500 km^2 and is continuing at a rate of 2 per cent annum (Benneh *et al* 1990). Overgrazing by livestock has resulted in large areas in the savanna and the Transition zones devoid of vegetative covers. These lead to erosion and low organic matter content of the soils.

2. **Nutrient mining**

   The problems associated with the use of fertilizers both organic and inorganic are many and are often beyond the solution of peasant farmers who form the majority of agricultural producers. The result is that most farmers do not use external input fertilizers and continue to crop the land and harvest the crop only to continuously deplete the land of nutrients. The land finally becomes completely exhausted and then abandoned, lack of financial resources and effective management practices in the predominantly smallholder production systems, have contributed to low or no fertilizer inputs to replenish nutrients lost from the soil as a result of crop uptake and nutrient leaching and soil erosion. Excessive exhaustion of nutrients from the soil through continuous cropping with little or no input through residue incorporation or other external inputs in the form of organic or inorganic fertilizers has become a serious yield limiting factor to the majority of farmers in the country.

3. **Bush burning**

   Indiscriminate annual bush burning, in the savanna zones and the slash and burn practices in the forest zones cause widespread destruction of vegetation. These do not only enhance deforestation but deprive the soil of organic matter that is important in fertility restoration in farmlands. Burning also destroys crops, eradicates herbage needed by animals as feed, destroys humus, increase erosion, and burn plant materials that would eventually supply the soil with organic matter (Fianu, 1975).

4. **Charcoal production and fuelwood harvesting**

   Many homes and factories in Ghana depend on the usage of charcoal and fuelwood as the main sources of energy causing extensive deforestation and soil exposure resulting in decrease of organic matter in the soil. Even in the cities where liquid petroleum gas may be available, preparation of some local dishes require the use of charcoal or fuelwood. In Accra and its environs, for example, 79 per cent of the households use only charcoal for their energy (Nketia 1988). It is also estimated by Benneh *et al* (1990) that the current domestic annual consumption of fuelwood and charcoal has reached 5,547,000 and 1,992,400 cubic meters respectively in Ghana.

5. **Short Fallow periods**

   In the past, cultivated lands were left fallow to regain fertility over sufficient periods of time. Lands were left fallow for over 15 years and by which time there would have been enough build up of plant nutrients before they are cultivated again. Presently, however, due to scarcity of land and the population pressure, fallow periods are reduced drastically and the lands are not allowed to remain fallow to build up enough nutrients before they are farmed again. Fallow periods these days seldom exceed 5 years.

Impact of low Soil Fertility on Agricultural Production

The low fertility nature of the soils of Ghana has far-reaching implications on agricultural productivity and the quality of life of the people. The growth in agriculture is crucial for the socio-economic development of the country as the majority of the people depend on the productivity of the land. Soil fertility decline has negatively impacted on agricultural production in many ways including decreases in food production, increases in agricultural production costs, reduction in fodder and animal manure production, reduction in soil biological activities, increases in food insecurity, food imports, and on foreign foods aids, reduction in agricultural exports, reduction in fuelwood production, increased unemployment and increase in rural urban migration. Soil fertility decline, therefore directly or indirectly exercises a lot of influences on the environment. Prominent among these are loss in bio-diversity, increase in deforestation increased environmental pollution and land degradation.

Soil Erosion

Since the dawn of time, soil has been eroded through the direct actions of rain and wind. Under protective cover of vegetation, the rate of soil loss is always low. Man’s activities, such as farming, hunting, animal rearing, timber extraction etc. have had great effects in causing soil degradation. This results in the removal of the protective vegetative cover, soil surface crusting, subsoil compaction, structural instability, soil impoverishment and many more soil limitations.

Ghanaian soils are susceptible to all forms of erosion. Numerous soil profile descriptions and analyses have revealed that most of our soil nutrients are bound within the topsoils. In most of our soils, organic matter and plant nutrient contents decrease sharply below the topsoils. It has also been found that the topsoils are of lighter textures, weak, fine to medium crumbs and granular structure and of friable consistence which make them erode very fast. The Soil Research Institute has alarming figures on areas affected by erosion. In the Interior Savanna Zone, 35,172 sq km are affected by slight to moderate sheet erosion; 27, 306 sq km by moderate to severe sheet and gully erosion and 33,494 sq km by moderate to very severe sheet and gully erosion. In the High Rainforest Zone which is even under the protection of thick forest vegetation, 2,745 sq km are susceptible to slight to moderate sheet erosion, 16,913 sq km to severe sheet and gully erosion, 3,675 sq km to moderate to very severe sheet and gully erosion, (Halm and Asiamah, 1986).

These high figures are indicative of the fragile nature of our soils. Thousands of tons of our productive soils are eroded away to waste every year.

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Chapter 3

Agroforestry and soil fertility maintenance

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Astract

Agroforestry was seen as a solution for shortening fallows, overgrazing, overexploitation of wood resources, erosion and wider climatic change all inducing lower soil fertility and unsustainable production. Amongst agroforestry practices tested are alley cropping, parkland systems, fodder banks, live fences, and biomass transfer. The most frequent aspects investigated of the aforementioned practices are tree effects on soil fertility, and on micro-climate and lately tree management in view to reduce the negative effects of trees on associated crops while safeguarding tree resource base. This chapter reviews the literature on the effects of agroforestry systems on soil fertility in Burkina Faso and discusses the role of trees in adding value to soil processes and reversing soil fertility depletion or maintaining it. Therefore, it highlights the key achievements of the studies on the role of agroforestry systems on soil fertility so that pertinent results can be used to design management options for better and sustainable production. The review also pointed out the less studied domains which constitute the future challenges in improving the role of trees on soil fertility.

Key words: *Agroforestry, soil properties, Burkina Faso*

Résumé

L'agroforesterie a été vue comme une solution à la réduction de la durée des jachères, au surpâturage, à la surexploitation des ressources en bois, à l'érosion et plus globalement au changement climatique, tous ces phénomènes induisant une faible fertilité des sols et donc une production non durable. Les pratiques agroforestières qui ont été testées sont les cultures en couloirs, les parcs agroforestiers, les banques fourragères, haies vives, et transfert de biomasse. Les aspects les plus fréquemment étudiés des pratiques susmentionnées sont les effets de l'arbre sur la fertilité du sol, et le micro-climant et plus récemment sur la gestion de l'arbre afin de réduire ses effets négatifs sur les cultures associées tout en sauvegardant la ressource arbre. Ce chapitre fait le point de la littérature sur les effets des systèmes agroforestiers sur la fertilité des sols au Burkina Faso et discute le rôle positif des arbres dans les processus pédologiques de restauration ou de maintien de la fertilité des sols. Il met donc en relief les résultats majeurs des études sur le rôle des systèmes agroforestiers sur la fertilité des sols afin que ceux-ci soient utilisés pour élaborer des options de gestion pour une production plus durable. La synthèse a aussi relève les domaines moins étudiés qui constituent les futurs défis de l'amélioration du rôle des arbres sur la fertilité des sols.

Mots clés: *Agroforesterie, propriétés des sols, Burkana Faso*

Introduction

The shortening fallows, overgrazing, overexploitation of wood resources, erosion and wider climatic change all typically contribute to lowered soil fertility and unsustainable production (Tilander, 1993). It has been suggested that agroforestry could counteract some of these problems. Therefore, agroforestry technologies like alley cropping, parklands, fodder banks, live fences, and biomass transfer have been tested or evaluated on various aspects (Kessler, 1992; Boffa, 1995; Tilander et al., 1995; Bayala, 2002). Alley cropping is a method of planting in which rows of a crop are sown between rows or hedges of nitrogen-fixing plants, the roots of which enrich the soil. This practice was tested in the central plateau of Burkina Faso but was not adopted by farmers (Tilander et al., 1995).

Parkland systems constitute a land use system in which trees are preserved in association with crops and/or livestock in spatial dispersed arrangement and where there are both ecological and economic interactions between the components (Bonkoungou et al., 1997). These systems are found all over Burkina Faso territory except in the extreme north with nevertheless different species composition according to the climatic zones and the local ethnic groups (Ouédraogo, 1995). The trees are preserved on farm fields because of the numerous products derived from them (food, wood, fodder, medicine, etc.) and the environmental services they provide (climatic amelioration, carbon sequestration, boundary markers) (Ouédraogo, 1995; Bonkoungou et al., 1997, Bayala et al., 2007).

Fodder banks are plantations at relatively close spacing of fast growing tree and/or shrub species resprouting well after pruning and capable to produce an important amount of biomass as fodder during the dry season when the quality of the grasses in proteins is low (Bonkoungou et al., 2002). This practice is not widespread as planted areas and the planted trees/shrubs tend to be dispersed. However, fodder species are preserved together with other species in parklands to provide green leaves during the dry season as source of proteins.

Live fencing is a way of establishing a boundary by planting a line of trees and/or shrubs at relatively close spacing to form a barrier (Huxley, 1997). The primary purpose of live fences is to control the movement of animals and people, however, they have proven to be extremely diverse, low risk systems that provide farmers with numerous benefits (Rocheleau et al., 1988). Besides their main function, living fences may provide fuelwood, fodder and food, act as wind breaks or enrich the soil, depending on the species used" (Westley, 1990). The practice is found around homestead gardens and in low lands around vegetable gardens by dams, reservoirs and rivers.

Biomass transfer is the transfer of plant biomass from outside the crop field into the field to improve the soil fertility and/or the SOM status. The transferred biomass is typically leaves and twigs from trees in the surroundings and is incorporated into the soil by hoeing or ploughing. This practice is found in the central and the northern parts of Burkina Faso where land degradation is severe. This practice is associated with mulching, which is a crop husbandry practice in which organic material is spread over the soil surface to influence the physical, chemical and biological properties of the soil and its micro-climate with the aim of improving the productivity of a site (Muller-Samann and Kotschi, 1994). Thus, key features of mulching are changes of soil physical and chemical properties, weed control and as a consequence improved or sustained crop production. Pruned materials from isolated trees, line or cluster planted trees/shrubs can be used for mulching.

Among the most frequent aspects investigated of the aforementioned practices are tree effects on soil fertility, and on micro-climate and lately tree management in view to reduce the negative effects of trees on associated crops while safeguarding tree resource base. This chapter reviews the literature on the effects of agroforestry systems on soil fertility in Burkina Faso and discusses the role of trees in adding value to soil processes and reversing soil fertility depletion or maintaining it.

As stated by Sanchez et al. (1997), there are four ways in which trees can have beneficial effects on soil properties, crop production and environmental protection. Trees in agroforestry systems (1) increase nutrients inputs to the soil, (2) enhance internal cycling, (3) decrease nutrient losses from the soil, and (4) provide environmental benefits. These beneficial effects are presented based on research findings in Burkina Faso with a focus on soil nitrogen and phosphorus because these are the most limiting nutrients. Before presenting these ways, changes in soil physical properties are discussed because they, like chemical properties, are equaly important in influencing the performance of agroforestry systems in Burkina Faso.

Therefore, the main aim of the present review is to highlight the key achievements of the studies on the role of agroforestry systems on soil fertility so that pertinent results can be used to design management options for better and sustainable production. The review also pointed out the less studied domains which constitute the future challenges in improving the role of trees on soil fertility.

Improved soil physical properties

Many studies on the effects of trees on soil dealt essentially with chemical properties (Kessler, 1992; Boffa, 1995; Jonsson, 1995; Tomlinson et al., 1995; Bayala, 2002). However, improvement of soil physical properties by the trees might be as important as the chemical properties in semi-arid areas because good physical properties enhance water holding capacity and efficient use of nutrients supplied.

Soil bulk density

The review of the literature revealed that only three studies dealt with the effects of trees on soil bulk density and the results showed a decrease in soil bulk density even though the figures were not always significantly different moving from the open area to the zone under tree influence. Bayala (2002) reported lower soil bulk density under *Vitellaria paradoxa* (1.59) and *Parkia biglobosa* (1.57) compared to the open area (1.62) in a parkland in Saponé village in the central plateau. Such trend is partly due to the organic matter inputs from trees mainly as leaves as attested by the results of some mulching experiments (Mando, 1997; Bayala et al., 2003). Using woody plant materials as mulch, Mando and Stroosnijder (1999) found a decrease of soil bulk density through increased soil organic matter, soil fauna biomass and activity. Mando and Stroosnijder (1999) concluded that in semi-arid areas physical effects of mulch on soil triggered by soil fauna are more important than chemical effects commonly expected.

However, mulching did not always result in a decrease in soil bulk density as reported by Bayala et al. (2003). These authors, in a mulching experiment comparing two doses of *Vitellaria paradoxa* leaves (T2=850 and T3=3400 kg ha^{-1}) and two doses of *Parkia biglobosa* leaves (T1=1200 and T2=4800 kg ha^{-1}) to a control (T1=no application of leaves), found no significant difference in soil bulk density among treatments (Table 1). Such results may be due to the quality of the materials used, the soil type and the duration of the experiment. Lack of statistical difference in such a study may also result from high variability in the data as suggested by the apparent difference between T3 (1.59) and T2 (1.66) under karité (*Vitellaria paradoxa)* mulch (Table 1).

Table 1: Soil physical properties according to tree species and treatments in topsoil (0-5 cm) in Saponé, Burkina Faso

	Vitellaria paradoxa			
	Bulk density	Porosity (%)	Ponding time (mn)	K_{sat} (cm day^{-1})
T1	1.63^{a}	37^{a}	1.55^{a}	91^{a}
T2	1.66^{a}	36^{a}	2.15^{a}	123^{a}
T3	1.59a	39^{a}	3.00^{a}	208^{a}
	Parkia biglobosa			
T1	1.54^{a}	41^{a}	1.86^{a}	138^{a}
T2	1.51^{a}	42^{a}	1.89^{a}	144^{a}
T3	1.54^{a}	41^{a}	2.47^{a}	171^{a}

Data in the same column with different letters are significantly difference at P<0.05

Source (Bayala et al., 2003)

Soil porosity

As a consequence of tree effects on soil bulk density, soils under trees in general displayed higher porosity compared to the soils in the open area. Thus, in a parkland higher porosity was found under *Vitellaria paradox*a (38.91%) and *Parkia biglobosa* (39.85%) compared to the open area (37.72%) in Saponé village in the central plateau (Bayala, 2002). Similarly in a mulching experiment using composite materials (organic materials of woody plants and straws), Mando (1997) observed an increase in soil porosity (41.1% for mulch treated plot vs 36.1% for untreated plot). He attributed this increase in soil porosity to the increase in the activity of termites because of favorable environment and food availability. This increase resulted in changes in soil structure with the chambers and channels accounting for 60% of the macroporosity in the 0-10 cm layer. The sealed surface was perforated by termites resulting in many visible open voids.

Thus, the triggering of termite activity on crusted soils leads to a change in the soil structure through three processes giving rise to three features according to Mando (1997):

- the transport of material to soil surface to construct sheetings for protection while searching for food;
- the excavation of irregularly-shaped voids open to the air (chambers and channels);
- the aggregation of the soil, particularly below 10 cm, through the construction of bridged grains coatings and crumbs that form the void fillings.

All three features have a critical influence on soil properties. The first process contributes to loosen the soil and this enables the soil to resist the degrading processes acting on the soil, such as water erosion and waterlogging (Mando, 1997).

Water infiltration and soil water content

Agroforestry studies in Burkina Faso have also focused on water infiltration that is influenced by both soil bulk density and porosity as well as by surface crust, surface storage, and saturated hydraulic conductivity. On plots mulched with composite materials of woody plants and cereal straws, Mando (1997) reported an increase in cumulative infiltration (251 mm vs 180 mm), infiltration expressed as a percentage of annual rainfall amount (43% vs 30%), final infiltration rates and soil water content on mulched plots compared to non-mulched plots. These improvements were attributed to an increase in saturated hydraulic conductivity ($1.06\ 10^{-5}$ m s^{-1} vs $0.14\ 10^{-5}$ m s^{-1}) and termite activity (Mando, 1997).

An experiment in parklands that measured the steady-state of infiltration capacity (IC) of soil with tension disc infiltrometer showed that average IC under *Vitellaria paradoxa* and *Faidherbia albida* was higher under trees (104 mm h^{-1}) than in the open area (69 mm h^{-1}). Additionally IC was higher in *Vitellaria paradoxa*-field (117 mm h^{-1}) compared to the value obtained in *Faidherbia albida*-field (58 mm h^{-1}) in

Dossi, a village in the Western Burkina Faso (Hansson, 2006). As a consequence of better infiltration and higher SOM content, soil water content was reported to be higher under trees than in the open area (Hansson, 2006).

In contrast to the two previous studies presented, no difference was observed between treatments in saturated hydraulic conductivity under *Vitellaria paradoxa* as well as under *Parkia biglobosa* as reported by Bayala et al. (2003) (Table 1). Yet, ponding time showed the highest values in T3 plots of *Vitellaria paradoxa* (208±117 cm day^{-1}) and *Parkia biglobosa* (171±39 cm day^{-1}) leaves (Table 1). Ponding time increased consistently with an increase in the quantity of leaf litter applied of both species (Table 1) and that may have led to increased infiltration while reducing soil erosion.

Some other studies focused on soil water content and the factors that can explain higher soil water content under trees compared to the open area. Yaméogo et al. (2005) recorded in the upper 0-30 cm, over the cropping seasons of 2000 and 2001, on average 8.36% of soil water content in the open area compared to 9.18% under *Borassus flabellifer* in Siniéna village, South-Western Burkina Faso. Similarly, Kaboré (2005) found in the upper 0-10 cm decreasing soil water content with rainy season average evolving from 18.9% under *Vitellaria paradoxa* to 16.2% at 2 m away from the crown edge and 14.0% in an open area in parklands of Saponé village. The figures under *Azadirachta indica* in Bulkiemdé province were 12.3% and 11% at its edge (Yélémou, 1993). Zoumboudré et al. (2005) recorded 10.7% in the upper 0-30 cm under *V. paradoxa* and 9.1% in the open area in Fada N'Gourma in the Eastern part of Burkina Faso. Boffa (1995) found similar trend in Thiougou village in the South of Burkina Faso. According to some of these authors, higher water content under trees is related to a lesser soil evaporation compared to the open area as reported by Jonsson (1995), reduced soil temperature (Yélémou, 1993; Yaméogo et al., 2005) and increased rain water reaching beneath trees because of canopy interception (Zomboudré et al., 2005). Jonsson (1995) found on average 22% lower evaporation under trees (*Vitellaria paradoxa* and *Parkia biglobosa*) whereas Yélémou (1993) recorded soil temperature of 29.6°C and 31.5°C under *Azadiractha indica* and at its edge, respectively. Finally, rain interception by *V. paradoxa* canopy led to an increase of 11.2% of rainwater under trees (Zoumboudré et al., 2005).

Impacts of the improvement of soil physical properties

The improvement of soil physical properties presented above is known to reduce runoff and erosion, to improve soil water holding capacity and to enhance nutrient use efficiency. As a consequence of all the above mentioned positive effects of trees on soil physical properties crop production is improved and sustained if other exacerbated competitions do not take place. Improvement of soil physical properties can also help to rehabilitate degraded crusted soil (Mando, 1997).

Improved soil chemical and biological properties

Good chemical properties are needed to make available the nutrients and ensure their balanced supply to crops. Such properties are in general associated with good biological properties ensuring the transformation of organic materials in mineral nutrients that can be taken up by crops. Three main processes leading to nutrient inputs from trees in agroforestry systems will be presented. These processes did not receive the same attention and consequently the number of studies that dealt with these aspects is not the same from one process to another. Some of these studies were carried out in research stations and some others in farmer's fields.

Biological nitrogen fixation

Alley cropping practices have failed in arid and semiarid tropics, where belowground competition for water between trees and crops frequently outweighed the benefits of soil enrichment (Ong and Leakey, 1999). Only one alley cropping experiment was reported in Burkina Faso but in this experiment the authors did not quantify the nitrogen fixed by the species used (Tilander et al., 1995).

Therefore, studies on nitrogen fixation were directed on the most famous species of parklands, i.e. *Faidherbia albida* (Del.) A. Chev. Like most of Leguminosae species, *F. albida* is associated with rhizobia-symbiotic soil bacteria, which form nitrogen-fixing root nodules (Lesueur et al., 1991). Without knowing the principle behind that, farmers in the village of Dossi in Western Burkina Faso agreed at 90% that this species improves soil fertility (Sanon, 1993). The host spectrum of 13 rhizobium strains of various origins showed that *F. albida* nodulated and the efficient nodules contributed to induce 45-72% higher shoot dry matter in inoculated plants, depending on the strains, than that of non-inoculated control plants after a two-month growing period under greenhouse conditions (Lesueur et al., 1991).

In a nursery experiment in Ouagadougou (Burkina Faso), Roupsard (1997) found 9% of fixed nitrogen (%Ndfa) for Dossi provenance (Burkina Faso), 13% for Matameye provenance (Niger) and 45% for Gihanga (Burundi) resulting in large differences in early growth. However, the most vigorous provenances that gave the highest fixation are known to be less tolerant to drought. Therefore a selection based only on the criteria of higher nitrogen fixation is risky for dry areas like Burkina Faso (Roupsard, 1997).

Despite the potential of this species, Roupsard (1997) showed that $\delta^{15}N$ displayed a decrease of 6 units in "δ" during the pick of nodulation phase (end of rainy season) compared to the end of the dry season. Such findings constitute an indication that *F. albida* fixed temporally in a narrow window corresponding to the initiation of leaves, while surface horizons are still moistened, the nitrogen of the upper layers can still be mobilized and when the nodules are abundant. The fact that this species can not fix during the dry season when it has the maximum of leaves may explain why it is classified as species of low potential for nitrogen fixation with the best fixation of 20 kg ha^{-1} $year^{-1}$ in field conditions (Dommergues, 1987). The inherent low P content of the soils in Burkina Faso can also limit N_2 fixation because of its role in the nitrogen fixation process.

Deep nitrate capture

Very few studies have addressed this process in Burkina Faso. The first study conducted by Roupsard et al. (1999) showed that despite a severe drought in the superficial soil layers, the predawn leaf water potential of *Faidherbia albida* dropped only to about – 0.5 MPa during the dry season, indicating only a moderate water stress. This is due to the fact that *F. albida* roots were distributed through the weathered rock, down to a depth of 7 m at the vicinity of a permanent water table. The isotopic composition of oxygen in the xylem sap ($\delta^{18}O$) remained very close to the values recorded in the water-table and switched towards the composition of superficial soil layers during early rains. All these data constitute an indication that adult trees of this species are capable of lifting up water from the water table when soil upper layers dry out. Together with the water, some nutrients are also taken up from deeper soil layers and recycled through tree litter.

In a second investigation, Bayala (2005) studied hydraulic lift (HL) in *Vitellaria paradoxa* (karité) and *Parkia biglobosa* (néré) during the dry season of 2003 and 2004 using thermocouple psychrometer and isotopic composition of water used by trees and crops. He found that soil water potential (ψ_s) measured in 2004 revealed distinct diurnal fluctuations with increasing values during the night and decreasing again the following day for both species. More than 70% and 60% of the psychrometer readings in the influence zones of karité and néré, respectively showed ψ_s values higher than 0.05 MPa, indicative of the occurrence of HL. The increasing trend from underneath tree to the open area of the values of ($\delta^{18}O$ for sorghum sap in 2003 and 2004 and for soil water in 2004 constitutes an indication of tree impact supporting HL occurrence in both karité and néré.

Both tree species in which HL occurs and the understorey plants can benefit from water redistribution in several ways among which the uptake of deep nutrients by trees and their recycling via litter for annual crops. The deep uptake of nutrients by trees is due to their deeper fine roots distribution compared to annuals even though the relative importance of such phenomenon is still unclear (Bayala et al., 2004). Higher soil moisture under trees can also increase mineralization rates and may help to maintain mycorrhizae, which can increase soil nutrient availability and plant nutrient uptake. In parkland systems, erratic and not well-distributed rains are common at sowing and grain filling periods. These are conditions under which hydraulic lift is likely to have a significant impact on trees and associated crops in terms of improving their survival and/or grain filling (Bayala, 2005). However, there is no guarantee that crops can actually take up the hydraulically lifted water as reported by Ludwig et al. (2004). According to these authors, although Acacia trees lifted large amount of water (Ludwig et al., 2003), a trenching experiment showed that grasses were still better of without tree roots (Ludwig et al., 2004).

Biomass transfer

Plant biomass from outside the crop field can be transferred into the field to improve the soil fertility and/or the SOM status. The transferred biomass is typically leaves and twigs from trees in the surroundings and is incorporated into the soil by hoeing or ploughing. Advantages of using leaves of trees/shrubs from outside the field are that these resources may be easily available (Tilander and Bonzi, 1997), they represent a true addition of nutrients to the field although at the expense of some other parts of the farm unless N-fixing legumes are used.

Appropriate mulching with high quality leaves may provide means to synchronize the timing of nutrient mineralization with that of crop demand. This may be achieved by mixing organic material of different quality or by manipulating the timing of application of high quality green manure (Palm and Sanchez, 1990). Biomass transfer also reflects specifically the aboveground contribution in improved fallow systems, and could, by comparison, help improving our understanding of belowground processes in improved fallow systems. A major disadvantage is that biomass transfer systems are very labour-intensive and thus not always economically feasible.

Organic material quality

Use of agroforestry tree prunings and litter for soil fertility improvement is one of the earliest benefits claimed in agroforestry-based cropping systems especially in addressing soil N deficiency. However the extent of soil improvement is related to the quality of the organic materials used because the nutrient content (especially N and P), lignin and polyphenol concentrations of litter strongly influence its rate of decomposition and nutrient release to the soil (Palm and Sanchez, 1990). There is a general consensus that net N mineralisation occurs if the N concentration is above 2% and immobilisation occurs below that concentration (Palm and Sanchez, 1990, 1991). Therefore, immobilization is likely to occur during the decomposing process of the leaves of *Acacia holosericia*, *E. camaldulensis, V. paradoxa* and *P. biglobsa* due to the fact that their N contents as reported by many authors is lower than 2% (Table 2). Nevertheless, the N content of a given species may differ depending on the sites as attested by the figures on *A. indica, P. biglobosa* and *A. holosericia* (Table 2). Such difference may also stem from differences in the chemical analyses methods used as well as to differences in the ages of leaves analysed. Reported data showed low phosphorus contents in all species. This was attributed to the inherent low content in this element in the soils of Burkina Faso indicating the need for its supply as mineral fertilizer. According to Zech and Weinstabel (1983), an application of P on *A. indica* increased slightly the content of leaves in this element and that was associated with an increase in N content (Table 2). When the content of K is high as reported by Yélémou (1993), the application of leaves as mulch contributes to the increase in pH of acid soils. In turn, immobilization is probable during the decomposition process of the leaves of *A. indica* because of their N content lower than 2%. Apart from N content, Palm and Rowland (1997) have developed a decision tree for organic matter management including lignin and phenol contents.

Table 2: Nutrient concentrations (%) in leaves of local and introduced species in Burkina Faso

Species	C%	N%	P%	K%	Ca%	Mg%	Ash	Lignin	Cellu-lose	Poly-phenols
Gmelina arborea (1a)		2.19	0.08	1.15	1.53	0.26				
Eucalyptus camaldulensis (1a)		1.54	0.09	1.20	0.66	0.16				
Azadirachta indica (1a)		2.37	0.10	1.34	2.01	0.41				
Azadiractha indica (1a*)		3.01	0.13	1.43	1.75	0.46				
Parkia biglobosa (1a)		1.88	0.14	0.97	0.48	0.15				
Dalbergia sissoo (1a)		2.78	0.46	1.58	1.18	0.31				
Prosopis juliflora (2a)		3.68	0.49	1.41	1.59	0.32				
Acacia holosericia (2a)		2.52	0.08	1.00	0.59	0.13				
Azadiractha indica (3b)		1.76	0.27	2.38	1.64	0.42				
Azadiractha indica (3c)		2.00	0.08	1.70						
Albizia lebbeck (3c)		2.80	0.11	1.30						
Azadiractha indica (3d)	49.00	2.10	0.10	1.30	1.80	0.47				
Acacia holosericia (3d)	53.00	1.70	0.06	0.68	0.73	0.21				
Vitellaria paradoxa (4e)	48.44	1.56	0.18	0.43	1.63	0.11	5.1	15.74	18.99	5.91
Parkia biglobosa (4e)	50.39	2.2	0.24	0.22	2.36	0.12	5.46	20.78	16.26	5.51

Sites: (1) = Gonsé, (2) = Djibo, (3) = Bulkiemdé, (4) = Saponé; * = application of P

Sources: (a) = Zech and Weinstabel (1983); b = Yélémou (1993); c = Tilander (1993); d= Tilander and Bonzi (1997); e = Bayala et al. (2005).

Decomposition rates

In Burkina Faso, very few decomposition experiments have been reported. Weight loss of *Azadiractha indica* decomposing leaves was 30% after one week during the rainy season according to Yélémou (1993). In another experiment, the decomposition constants of the leaves of *Vitellaria paradoxa* (karité) and *Parkia biglobosa* (néré) ranged from 0.08 to 0.71 month^{-1} (Bayala et al., 2005) (Table 3). The values of r^2 of the exponential equations for decomposition against time ranged between 51% and 79% for néré, and between 79% and 98% for karité. Combining leaves of both species with either urea or compost did not improve the rates of decomposition suggesting that fertilizers were not capable of accelerating decomposition of leaf litter of these two species (Bayala et al., 2005). On the other hand these authors showed that incorporating leaf litter under soil surface led to faster decomposition than the non buried material (Table 3).

Table 3: Decomposition and nutrient loss constants, k, for leaves of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) as determined from litter tube experiment in Saponé, Burkina Faso*

Species	Decomposition	N release	P release	K release
Karité	0.23[a]	**0.21**[a]	0.30[a]	**0.42**[a]
Néré	0.22[a]	**0.27**[b]	0.33[a]	**0.30**[b]
Position				
Upper	**0.19**[a]	**0.21**[a]	**0.28**[a]	**0.31**[a]
Under	**0.25**[b]	**0.26**[b]	**0.35**[b]	**0.40**[b]
Fertilizer				
No	0.25[a]	0.21[a]	0.32[a]	0.39[a]
Urea	0.22[a]	0.21[a]	0.32[a]	0.37[a]
Compost	0.19[a]	0.26[a]	0.30[a]	0.32[a]

Data in the same columns with different letters are statistically different at $P < 0.05$ using pairwise t-tests;
* Shows results in Bold where significant changes occurred

Source Bayala et al. (2005)

Nutrient release rates

In general, the greater the N content, the lower the lignin content. However, the data available indicate a general low N content of most tree species (Table 2). A more complex effect of these elements on N release is the fact that their contents become dynamic along the decomposition process. As decomposition proceeds, the proportion of lignin increases as microbes preferentially metabolise other chemical fractions thus increasing the lignin control of mass loss and nutrient release rates of organic resources (Palm and Sanchez, 1990).

In a decomposition experiment, Bayala et al. (2005) noticed that leaves of *Parkia biglobosa* (néré) with a polyphenol:N ratio of 3.8 (Table 3) released N faster than those of *Vitellaria paradoxa* (karité) whereas the situation was the reverse for K (Table 3). Again as for the decomposition rate, burying the leaves accelerated the release of all nutrients in this experiment while incorporating urea or compost showed no significant effect (Table 3). The pattern of N release in néré was similar to the patterns of the other two nutrients showing two phases coinciding roughly with rainy and dry periods in Burkina Faso (Bayala et al., 2005). In the first phase (rainy period) which lasted for 3 months, the concentrations of nutrients decreased more sharply than in the second phase (dry period). The trend of nutrient release was also sharper in néré compared with karité in which there was no distinction between the two phases. During the first 3 months, corresponding to the cropping season in the study area, the release of N, P and K ranged from 40 to 80% for karité and from 75% to 90% for néré, respectively (Bayala et al., 2005).

Mulching effects on soil chemical properties

Despite the focus of the studies on the effects of mulching experiments on soil chemical properties, results available in Burkina Faso do not always meet the expectations of improving chemical properties as reported by Bayala et al. (2003). These authors, in a mulching experiment comparing two doses of *Vitellaria paradoxa* leaves (T2=850 and T3=3400 kg ha^{-1}) and two doses of *Parkia biglobosa* leaves (T1=1200 and T2=4800 kg ha^{-1}) to a control (T1=no application of leaves) found an increase of soil C, and N with an increasing amount of *Parkia biglobosa* mulch even though the difference was not significant between plots for N (Table 4). These authors also reported a non significant increase in nutrient contents with an increasing amount of the *Vitellaria paradoxa* material applied except for K (Table 4).

Table 4: Soil chemical properties according to tree species and treatments in top soil (0-10 cm) in Saponé, Burkina Faso

	Parkia biglobosa						
	C (g kg^{-1})	OM (%)	N (g kg^{-1})	C/N	P-available (mg kg^{-1})	P-total (mg kg^{-1})	K-total (mg kg^{-1})
T1	4.64^{a}	0.80^{a}	0.28^{a}	17^{a}	10^{a}	78^{a}	357^{a}
T2	5.69^{a}	0.98^{a}	0.33^{a}	17^{a}	7^{a}	84^{a}	295^{a}
T3	10.14^{b}	1.75^{b}	0.38^{a}	29^{b}	12^{a}	74^{a}	320^{a}
	Vitellaria paradoxa						
	C (g kg^{-1})	OM (%)	N (g kg^{-1})	C/N	P-available (mg kg^{-1})	P-total (mg kg^{-1})	K-total (mg kg^{-1})
T1	5.89^{a}	1.02^{a}	0.29^{a}	22^{a}	9^{a}	112^{a}	348^{a}
T2	6.27^{a}	1.08^{a}	0.32^{a}	20^{a}	9^{a}	133^{a}	284^{a}
T3	6.98^{a}	1.20^{a}	0.39^{a}	18^{a}	10^{a}	150^{a}	343^{a}

Data in the same column with different letters are significantly different at $P<0.05$
Source: Bayala et al. (2003)

In her study using leaves of *A. indica* and *A. lebbeck*, Tilander (1993) did not find a clear relation between the effects of the mulch on soil chemical properties and crop production even though contents of organic matter, total N and K were higher in leaf-treated plots than in the untreated ones after two growing seasons (Table 5). This may be due to initial differences between plots, direct uptake of nutrients released from the mulch, or to the fact that the presence of leaves enhanced the nutrient use efficiency by the crops.

Table 5: Soil fertility in control and mulch-treated plots after two growing seasons in Bulkiemdé province, Burkina Faso

Nutrients	OM (%)	N (%)	P (ppm)	K (me $100g^{-1}$)	Ca (me $100g^{-1}$)	Mg (me $100g^{-1}$)	CEC (me $100g^{-1}$)
Control plots	0.67	0.03	0.71	0.08	1.10	0.41	3.00
Mulch treated plots	0.79*	0.04*	0.79	0.11*	1.20	0.40	3.00

** Significantly different from the control (P<0.005)*
Adapted from Tilander (1993)

Despite the fact that mulching did not always strongly improve soil properties (Tilander, 1993; Bayala et al., 2003), the increase in crop production associated with mulching constitutes an indication that it can be used to lengthen the cultivation phase. The main constraint of the mulching practice remains the availability of the organic materials in quantity and quality. Furthermore, better management techniques or the organic materials are still needed to get the maximum benefit both in terms of the quantity of crop produced and the sustainability of tree-based cropping systems.

Enhanced nutrient cycling

Soil organic nitrogen

Roots constitute a substantial proportion of net primary production occurring belowground. In terms of root extension, Tomlinson et al. (1998) showed that *P. biglobosa* (néré) tree roots extended to at least 10 m from the trunk and could cover an area eight times that of the crown. Jonsson (1995) found large roots of *V. paradoxa* and *P. biglobosa* 60 m away from the trunk. The more difficult the environmental conditions the longer are these lateral roots (Boffa, 1999). Studies done on fine roots distribution showed that root mass decreases with distance from the trunk (Tomlinson et al. 1998; Bayala et al., 2004). According to Bayala et al. (2004), fine roots were also found concentrated in the upper 0-20 cm at 59% (0.477 cm cm^{-3}) and 69% (0.447 cm cm^{-3}) for *V. paradoxa* and *P. biglobosa,* respectively.

In addition to the decayed biomass of roots, leaves also fall and decompose. Bayala (2002) evaluated the leaf biomass after pruning *Vitellaria paradoxa* (karité) and *Parkia biglobosa* (néré). He found that karité produced less dry matter of leaf biomass at individual level (68.2±4.9 kg $tree^{-1}$) than néré (138.6±22.9 kg $tree^{-1}$) but when considering the densities of these two species in the study site, leaf biomass per tree was equivalent to 275 kg ha^{-1} and 124 kg ha^{-1} for karité and néré, respectively. Based on litter basket collection under four karité trees (mean DBH 42 cm) in Thiougou, Southern Burkina Faso, leaf production was estimated at 29 kg per tree (Boffa, 1999), which was twice lower than the value in the study of Bayala (2002). Such differences may be due to differences in the methods used, and tree age or size.

Because of the above mentioned inputs and fixed nitrogen by legumes, higher soil nitrogen content has been found by many authors in parklands (Depommier et al., 1992; Kessler, 1992; Boffa, 1995; Tomlinson et al., 1995; Depommier, 1996; Jonsson et al., 1999; Bayala et al., 2002) and in alley cropping (Tilander et al., 1995). A part from the recycling of nutrients via leaves and roots decomposition other potential sources exist that contribute to increased soil nitrogen under trees (faeces of birds resting on trees, faeces of animal resting under trees, deposits, etc.). Despite the contributions of other sources, the correlations between %N and %C (r^2=0.97, $p<0.001$) reported by Jonsson (1995) may indicate a higher contribution of trees compared to the other sources. Bayala et al. (2002) also found a highly significant correlation between C and N (correlation coefficient = 0.59 at $P<0.001$). A general decreasing trend of C and N contents going from tree trunk to the open area was registered by Depommier et al. (1992) and Bayala et al. (2002) (Tables 6&8). In the only one alley cropping experiment reported, Tilander et al. (1995) obtained higher soil organic matter and nitrogen contents in soil samples collected close to tree lines over two cropping seasons (Table 7). All these findings constitute an indication of the potential important contribution of trees to the higher N content measured under trees in semi-arid conditions.

Table 6: Soil properties according to tree species and distance from the trunk in top soil (0-10 cm) in Saponé, Burkina Faso

Variable	**Zones around trees**			
Karité	**A**	**B**	**C**	**D**
Carbon (g kg^{-1})	6.12	5.53	5.28	5.05
OM (%)	1.07	0.95	0.90	0.88
N-total (g kg^{-1})	0.45	0.38	0.37	0.35
P-available (mg kg^{-1})	3.62	4.79	4.13	3.69
P-total (mg kg^{-1})	110.97	96.70	91.80	85.03
Néré				
Carbon (g kg^{-1})	6.22	6.08	5.59	5.30
OM (%)	1.06	1.04	0.97	0.92
N-total (g kg^{-1})	0.42	0.40	0.39	0.40
P-available (mg kg^{-1})	3.77	3.96	4.07	5.16
P-total (mg kg^{-1})	99.60	77.80	82.05	112.34

A = 0 to 2 m from the trunk; B = from 2 m to half diameter of the crown ; C = from half diameter to the edge of the crown ; D = from the edge of the crown to 2 m outside of the crown
Adapted from Bayala et al. (2002)

Table 7: Comparisons between soil properties at the start of the growing season 1987 with data obtained after harvest in 1989 in alleys of *Albizia lebbeck, Azadirachta indica* and *Leucaena leucocephala* at two spacings in Bulkiemdé province, Burkina Faso

Species	*Albizia lebbeck*				*Azadiractha indica*				*Leucaena leucocephala*			
Spacing	1 x 5 m		2 x 8 m		1 x 5 m		2 x 8 m		1 x 5 m		2 x 8 m	
Year	87	89	87	89	87	89	87	89	87	89	87	89
OM (%)	0.80	1.00	0.62	0.65	0.94	0.97	0.94	0.90	0.88	0.94	0.64	0.60
Total N (%)	0.03	0.04	0.02	0.04	0.04	0.06	0.04	0.03	0.04	0.05	0.03	0.02
Available P (ppm)	1.0	0.93	1.1	0.82	1.3	1.2	1.4	1.0	0.92	0.64	1.1	0.89
Total P (ppm)	72	41	54	29	77	48	69	44	67	45	54	36

Adapted from Tilander et al. (1995)

Soil organic phosphorus

Phosphorus (P) is one the most limiting factors in the soils of the semi-arid areas of West Africa justifying the interest in assessing the impacts of trees on soil P in Burkina Faso. Boffa (1995) in Thiougou village found 75 mg kg^{-1} of soil total P at *Vitellaria paradoxa* crown edge and 58 mg kg^{-1} at mid-transect between two individuals of the same tree species. Similarly, many other authors found higher P content under trees compared to the open area in parklands (Depommier et al., 1992; Jonsson, 1995; Depommier, 1996; Bayala et al., 2002). Examples of such pattern are given in Table 6 (Bayala et al., 2002) and Table 8 (Depommier et al., 1992). More importantly, Jonsson (1995) established a correlation between total %N and exchangeable P, and between %C and P_{Olsen} (r^2=0.63, $p<0.001$ for both correlations). Such correlations constitute an indication of the contribution of trees in replenishing soil P via their litter and decaying roots. However, trees may deplete soil P in its surroundings depending on the species (Bayala et al., 2003) or the planting density (Tilander et al., 1995; Tilander, 1996). The low P content found for instance under *P. biglobosa* both by Tomlinson et al. (1995) and Bayala et al. (2002) was attributed by Tomlinson et al. (1995) to the presence of endomycorrhizal symbioses. These symbioses certainly enable the root system of this species to exploit the existing P more efficiently and thus reduce its availability. Whatever is the species, if densely planted as in alley cropping, trees also seem to deplete soil P as suggested by the findings of Tilander et al. (1995) and Tilander (1996) in Bulkiemdé province (Table 7). This trend may be due to both the inherent low soil P content of the soils of Burkina Faso and the immobilization of an increasing amount of this nutrient in woody parts for example those exported as firewood after each pruning. There is therefore a need to supply inorganic P if the alley cropping system is to be promoted to produce biomass for mulching in semi-arid zones with fast growing species like those tested by Tilander et al. (1995).

Table 8: Chemical characteristics of soil from two horizons under and away F. *albida* canopies at Watinoma, Burkina Faso

	0-20 cm		20-40 cm	
Soil parameters	Under canopy	Open area	Under canopy	Open area
C (%)	1.1	0.8	0.8	2.2
N (%)	1.3	0.9	1.0	0.8
P (ppm)	22.0	18.0	8.5	7.8
K (meq 100 g^{-1})	0.7	0.4	0.6	0.4
CEC	8.5	7.4	9.4	9.1

Adapted from Depommier et al. (1992)

Decreased soil erosion and nutrient losses from the soil

There is very limited quantitative environmental research on the shelter efficiency of agroforestry systems including parklands in Burkina Faso. Stigter et al. (1993) observed that little progress had been made in trees related wind and water protection research in Africa. Thus the only case we can mention was conducted to assess water erosion by Yaméogo et al. (2006). Observations on soil erosion have been made to compare the effects of sole maize and *Borassus flabellifer* associated with maize (Yaméogo et al., 2006). A stake, graduated each 10 cm, was buried up to 30 cm and the thickness of the soil removed was assessed every two weeks in Siniéna village, South-Western of Burkina Faso. The results revealed that the presence of Borassus trees resulted in a reduction of soil losses compared to the open area as the rainy season proceeded (Table 9). These results are in line with the findings of a survey reported by Sanon (1993) on the role of *F. albida* parklands in the reduction of wind erosion during the dry season because of the inverse phenology of *F. albida*. Those effects may be due to the physical barrier provided by the trees and also to the improved soil organic matter by the accumulated organic materials from the trees. It is well known that SOM plays many roles in soil improvement as source of nutrients and negative charge retaining base cations and as improver of soil physical conditions (water holding capacity, permeability and aeration). The later aspect contribute to ameliorating soil structure leading to a reduction of soil and nutrient losses (Hansson, 2006). Despite the importance of studies like the one conducted by Yaméogo et al. (2006), there is a need for more quantitative and detailed studies of agroforestry systems beyond the scale of single trees to be able to give better insight of the functioning of these systems with the respect to soil erosion. Such investigations should involve the wind and the water (rain) effects as well as the effects of the mulch from leaf litter of trees.

Table 9: Length of the stake (cm) remaining buried in Siniéna village, South-Western Burkina Faso

Period	Under *Borassus flabellifer*	Open area
Mid-July	30	30
End-July	27.95	26.35
Mid-August	26.04	23.49
End-August	24.47	22.08

Adapted from Yaméogo et al. (2006)

Induced environmental benefits

The most common induced environmental benefits of agroforestry systems include biodiversity conservation and carbon sequestration. If the first aspect has been well studied (mainly for tree diversity), there is a dearth of data on the second aspect in semi-arid zones.

Biodiversity conservation

All agroforestry systems are composed of at least two components: crops and trees. Trees are more often composed of many species making agroforestry systems more diverse than crop plots or plantations. For example, parklands are more often dominated by one or two tree species. However, parkland system is reported to be extremely diverse in species composition depending on the original vegetation from which it is derived, the needs of farmers and the uses of species known by the locality's ethnic group. For instance, Gijsbers et al. (1994) and Boffa (1995) recorded 43 and 74 tree species, respectively in parklands of North and South of Burkina Faso. Bayala and Lamien (1995; 1997) recorded 54 species in Yasso village in the West of Burkina and 48 species in Dimolo village in the South of Burkina. This is claimed to be the most well studied aspect of the biodiversity in agroforestry systems in Burkina Faso (Yaméogo and Nikiéma, 1995; Nikiéma, 2004; 2005, Abegg et al., 2006). Some of the preserved or planted species in parklands are fodder species and are pruned for livestock during the dry season when the nutritional quality of the grasses is low.

In addition to tree diversity, agroforestry systems help to conserve plant and animal biodiversity by offering diverse niches both for aboveground and belowground parts. In the belowground biodiversity conservation domain there is still a lot to be done both qualitatively and quantitatively. In this domain, the reported studies on biological activity give an indication of higher number of micro-organisms but not of the diversity of these micro-organisms. A case study aiming at assessing the biological activity (BA) and microbial biomass (MB) under trees of different species was carried out in Burkina at different sites of the country from the Northern to the Southern parts (INERA, 2000). The results revealed a higher biological activity and microbial biomass in the zone closer to tree trunk in comparison with the zone more distant from tree trunk (Table 10). The trees, by improving the micro-climate in their influence zone and increasing the accumulation of soil organic matter (source of food for the micro-organisms), create certainly more favourable conditions for the micro-organisms in comparison with the open area.

Agroforestry can be used in the reclamation of degraded land by using technique like biomass transfer but to date very few data exist with this respect. Experimental data on use of leaf biomass from shrubs as mulch showed improvement of soil physical and chemical properties, as well as microclimatic characteristics leading to better vegetation rehabilitation on bare soil (Mando and Stroosnijder, 1999). These authors observed a vegetation cover of 33% with a number of species reaching 12, two years after applying woody materials of *Pterocarpus lucens* on a bare and crusted soil.

Table 10: Global biological activity (C-CO_2 mg 100 g^{-1} soil) and microbial biomass (C-CO_2 mg 100 g^{-1} soil) of the 0-20 cm depth in different sites in Burkina Faso

Zones	Sites	Species	Biological activity		Microbial biomass	
			Close	Away	Close	Away
North	Djibo	*Acacia Senegal*	11.0	12.7	8.8	6.6
		Ziziphus mauritiana	12.3	14.1	9.2	7.4
		Bombax costatum	14.8	ND	7.4	ND
Centre	Saponé	*Vitellaria paradoxa*	7.3	7.5	5.3	4.6
		Parkia biglobosa	13.0	11.1	9.8	5.9
	Saria	*Faidherbia albida*	10.3	8.9	ND	ND
		Albizia lebbeck	12.6	7.5	ND	ND
		Prosopis Africana	10.3	8.8	ND	ND
South	Farako-bâ	*Eucalyptus camaldulensis*	17.5	ND	9.8	ND
		Gmelina arborea	16.5	ND	10.7	ND
		Anogeissus leiocarpus	14.0	11.9	8.5	8.9
		Azadiractha indica	16.8	ND	12.3	ND
		Faidherbia albida	12.4	16.0	5.1	11.1
		Vitellaria paradoxa	12.7	14.0	9.4	9.5

ND = not determined Source INERA (2000)

Carbon sequestration

Trees preserved or introduced in agroforestry systems contribute to reduce the carbon in the atmosphere by accumulating biomass and carbon via the photosynthesis process. This contribution of trees to soil carbon build up is however not well studied. As earlier mentioned trees increase soil fertility and soil carbon via the recycling of their litter and roots. However, increase in soil fertility parameters by trees has been seen as a controversial issue because trees may have simply grown in spots of higher fertility. Therefore, studies were carried to elucidate this point by separating the contribution of trees from that of other components (crops, and weeds) of agroforestry systems. For such investigation, Nyberg and Hogberg (1995) recommended ^{13}C natural abundance as a particularly sensitive tool to evaluate the influence of trees on soil organic matter.

Jonsson (1995) measured the natural abundance of ^{13}C in topsoil and found lower values under karité and néré trees than on control plots. Consequently, she found that the fraction of C-derived from C_3 plants, calculated based on $\overline{\sigma}^{13}C$, was higher under trees than in the open due to litter from C_3 plants. Similarly, Bayala et al. (2006) studied the relative contributions of trees and crops to soil organic carbon in the soils of a parkland of karité (*Vitallaria paradoxa* C.F. Gaertn) and néré (*Parkia biglobosa* (Jacq.) Benth.). In parkland systems, fertility (physical, chemical and biological) gradients around trees have been attributed by some authors to a priori differences in fertility, allowing for better tree establishment on richer sites (Brouwer et al., 1993; Van Noordwijk and Ong, 1999). In reverse, other workers believed that these gradients are due to the contribution of trees to the formation of soil organic matter through litter and decay of roots (Breman and Kessler, 1995; Belsky and Amundson 1998). Measurements of the variations in the ^{13}C isotopic composition allowed for a distinction between tree (C_3) derived C and crop and grass (C_4) derived C in the total soil organic C content. The organic carbon contents of the soils were recorded under the two species at two soil depths and at five distances going from tree trunk to the open area and their C isotopic signatures were analyzed. The results showed that soil carbon contents under karité (6.43 g kg^{-1}) and néré (5.65 g kg^{-1}) were higher than in the open area (4.09 g kg^{-1}). The $\overline{\sigma}^{13}C$ of soil C was higher in the open area (-17.5‰) compared with the values obtained under karité (-20.2‰) and néré (-20.1‰). The C_4-derived soil C was approximately constant, and the differences in total soil C were fully explained by the C_3 (tree) contributions to soil carbon of 4.01, 3.02, 1.53 g kg^{-1} under karité, néré and in the open area, respectively. These results show that trees in parklands have a direct positive contribution to soil carbon content, justifying the need to encourage the maintenance of trees in these systems in semi-arid environments where the carbon content of soil appears to be the priority limiting factor for crop growth.

The aforementioned findings constitute some proofs that trees contribute to the increase and maintenance of soil carbon content and therefore showing their contribution to carbon sequestration in semi-arid zones. The soil carbon is a major factor controlling organic matter formation and nutrient release.

Conclusion

Trees have a different impact on soil properties than annual crops, because of their longer residence time, and larger biomass accumulation. Therefore emerging data is showing that successful agroforestry systems increase nutrient inputs, enhance internal flows, decrease nutrient losses and provide environmental benefits when the competition for growth resources between trees and crop component is well managed. From existing data in Burkina Faso, the effects of trees on soil properties in agroforestry systems are generally positive. Despite such beneficial effects, the subsequent impacts of trees on associated crops, mainly cereals were reported to be negative in some cases or neutral in some others. The negative effects are due to either shading or competition for water and nutrients. In such circumstances, it is imperative to consider the effects of trees on soil properties in relation to appropriate management tools of tree component to increase the overall production and to sustain the systems.

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Chapter 4

Soil Organic Matter and Nitrogen in Ghanaian Soils: A review

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Abstract

Soil organic matter (SOM) and native soil nitrogen are major contributors to production in smallholder agro-pastoral farming systems in Africa where agricultural production rely mainly on inherent soil fertility. The levels of these two soil components to a large extent influence the productivity of agricultural lands for most crops in these areas. We reviewed the levels, distribution and changes in SOM and total N in Ghanaian soils as reflected in studies conducted over the years. The amount of SOM in soils of Ghana varies widely depending on the agro-ecology, soil type, drainage, land use and management systems. Under similar land use types the amount of SOM in savanna soils is generally lower than those in the transition and forest soils. Where land use intensity is low, SOM in forest and transitions soils range between 4% and 8% but the figure is much lower in intensely cultivated lands. In savanna areas values around 1% are common on cultivated soils. Cultivation has been shown to depress SOM up to 500% in both forest and savanna soils within a period of 5 years after natural vegetation conversion. In the savanna areas of northern Ghana, SOM is maintained with farm yard manure and household refuse at about 3% on fields around the homestead (compound farms) compared with a mean of about 0.6% on bush farms. The amount of native soil N follows the same trend as SOM. Forest soils contain between 0.1%-0.5% total N while savanna soils contain 0.02% - 0.09%. For most forest soils in Ghana, it is possible to obtain a good yield of cereals without any soil amendment particularly if the soil has not been cultivated for more than 5 years. Good cereal yields can be obtained in savanna soils only with soil amendment. In order to maintain or increase SOM and N in soils of Ghana, conservation tillage with leguminous cover crops, use of crop residues and farm yard manure needs to be encouraged. Increased use of mineral fertilizer will supplement N supply and contribute to SOM maintenance through increased below ground biomass production.

Key words: *Legumes, soil organic matter, soil nitrogen, biomass, Ghana*

Résumé

La matière organique du sol (MOS) et de l'azote natif sont les elements majeurs contribuant – la production dans les systèmes agro-pastotaux des paysans en Afrique o_ la production agricole est essentiellement liee a la fertilité inhérente aux sols. Les niveaux de ces deux composants du sol, dans une large mesure jouent sur la productivité des terres agricoles pour la plupart des cultures dans ces zones. Nous avons examiné les niveaux, la distribution et l'évolution de la MOS et de l'azote total dans les sols ghanéens sur des études menées durant plusieurs années. Le taux de MOS dans les sols du Ghana varie considérablement en function de l'agro-écologie, du type de sol, du drainage, de l'utilisation des terres et des systèmes de gestion. Dans les mêmes conditions d'exploitation, le taux de MOS dans les sols de la savane est généralement inférieure – celle de la zone de transition et les sols forestiers. Lorsque l'intensité d'utilisation des terres est faible, la MOS dans les sols de foret et des zones de transition se situent entre 4% et 8% mais devient beaucoup plus faible dans les terres qui sonts intensivement exploitées. Dans les zones de la savane, ces valeurs sont de l'ordre de 1% sur les sols cultivés. Il a été demontré que l'exploitation baisse la MOS jusqu'_ 500% sur les sols de forêt et de savane sur une periode de 5 ans après la conversion de la végétation naturelle. Dans les zones de savane au nord du Ghana, la MOS est maintenue dans le fumier et les ordures ménagères á environ 3% sur les champs antour des habitations contre une moyenne d'environ 0.6% sur les champs de brousse. Le taux de l'azote natif du sol suit la même tendance que la MOS. Les sols forestiers contiennent 0.1% – 0.5% d'azote total alors que les sols de savane n'en contiennent que 0.02% – 0.09%. Pour la plupart des sols forestiers au Ghana, it est possible d'obtenir un bon rendement céréalier sans amendment en particulier si le sol n'a pas été cultivé pendant plus de 5 ans. Des bons rendements céréaliers peuvent étre obtenus sur les sols de savane avec un amendment des sols seulement. Afin de maintenir ou d'accroître la MOS et l'azote dans les sols du Ghana, la conservation de la surface du sol avec la culture de converture léguminueses, l'utilisation des résidus de récolte et du fumier doivent étre encouragé. L'utilisation accrue des engrais minéraux fournira l'azote requis et contribuera – l'entretien de la MOS par une augmentation appreciable de la production de biomasse racinaire.

Mots clés: *léguminueses, La matière organique du sol, l'azote du sol, biomasse, Ghana*

Introduction

Soil organic matter (SOM) is a generic term for organic constituents in the soil, including dead, undecayed plant and animal tissues, their decayed and partial decomposition products and the soil biomass. The decayed substances are referred to as humus. Very often, the term humus is used synonymously with soil organic matter resulting in ambiguity regarding the specific component being referred to. In mineral soils, organic matter content is 3 - 5% by weight in the top soil.

Soil organic matter is a major contributor to agricultural production particularly in Africa and the developing world where production systems rely heavily on inherent soil fertility. Its influence on soil properties and consequently on plant growth, however, is far greater than the low percentage would indicate. The benefits of SOM derive from its nutritional, physico-chemical and biological functions in the soil. It is a labile resource and a source and sink simultaneous for nutrient elements such as N, P and S for plant growth; (Smith and Woomer, 1993). It contributes indirectly to plant nutrition by serving as a source of energy for N_2-fixing bacteria and other organisms. Organic matter is important for the soil physical conditions such as the structure. The deterioration of structure associated with intensive tillage is usually less severe in soils adequately supplied with organic matter. When organic matter is lost, the soil tends to be hard and compact. Organic matter increases aggregation, permeability, infiltration and water-holding capacity of soils. The improved granulation caused by organic matter enhances the formation of large pores and increased percolation of water which leads to good aeration and adequate supply of oxygen for efficient plant growth.

In low activity clays as those found in the tropics and for that matter Ghana, SOM provides up to 70% of the exchange capacity. It has a high cation exchange capacity of 150-200 cmol+ kg^{-1} soil compared with 9 cmol+ kg^{-1} of the clay (de Endredy and Montgomery, 1954).

Soil organic matter serves as a source of energy for actinomycetes, fungi and other macro-fauna such as earthworms and other organisms. It can have direct physiological effect on plant growth. Some phenolic compounds have phytotoxic properties while others such as auxins enhance plant growth. Many of the factors influencing the incidence of pathogenic organisms in soils are directly influenced by organic matter. For example, large supply of SOM may favour the growth of saprophytic organisms relative to parasitic ones. Biologically active compounds in soils such as antibiotics and certain phenolic acids may enhance the ability of certain plants to resist attack by pathogens.

Levels of Soil Organic Matter in Ghanaian soils

The amount of organic matter in mineral soils varies widely as it depends on the agro-ecology, soil type, drainage, land use and management systems. Ghana has six main agro-ecological zones, namely, the rain forest, the deciduous forest, the transition, the Guinea savanna, the Sudan savanna and the coastal savanna zones. The level of organic carbon in the surface horizon is fairly high in mature and secondary forests but falls rapidly with depth. In savanna the level in the 0-15 cm layer is much lower than in forest, but the fall in the 15-30 cm layer is relatively less steep. The amount of organic carbon in the topsoil of forest soil is about 12 times more than the savanna soils. According to Greenland and Nye (1959), the level of organic matter in forest is reduced by a rather high rate of decomposition. In savannas, the rate of decomposition under grasses is low, but the supply of fresh material is greatly reduced by annual burning. In general higher levels of organic matter were found in forest soils compared with savanna soils under similar management. In the rain forest zone of Western Region, Fosu (1982) recorded organic matter levels between

1.6% to 6.1% on fields under cocoa plantations and 1.9% to 3.3% on adjacent fields of thicket that were abandoned for 5 years after periods of cultivation of food crops. The older cocoa farms with several years of leaf litter had the highest organic matter content while the younger ones intercropped with food crops had lower organic matter content. Organic matter content was 4 -7% in the top soils of semi deciduous forest ecology with low land use intensity (Table 1; Owusu-Bennoah et al., 2000). The relatively high organic matter content was due to accumulation from leaf litter.

Table 1: Organic matter content in semi-deciduous forest soils of Ghana.

Soil series (Ghana system)	FAO revised legend (1988)	Slope Position	Depth (cm)	Organic matter (%)
Bekwai	Ferric Acrisol	Upper slope	0-7	6.36
Nzima	Haplic Acrisol	Upper slope	0-8	7.14
Kokofu	Haplic Lixisol	Middle slope	0-7	4.38
Kakum	Gleyic Acrisol	Middle slope	0-10	4.52
Temang	Eutric Gleysol	Bottom slope	0-5	4.74
Oda	Eutric Gleysol	Bottom slope	0-8	4.52

Source: Owusu-Bennoah et al., 2000.

Within the same agro-ecology wide range of organic matter content of soils exists depending on vegetation and land use (Adu and Mensah-Ansah, 1995). On uncultivated Ferric Acrisol under thicket, organic matter content of 8.0% was recorded while on a Dystric Nitisol under forest vegetation the above authors recorded organic matter content of 4.3%. Both soils are sandy clay loam. On a nearby Gleyic Arenosol under broken forest, organic matter content was only 1.0%. This soil was under cultivation for several years leading to the marked depression in the organic matter content.

Organic matter is lower in the transition zones, savannas and cultivated fields than the forest zones. In the transition areas of the Afram basin, organic matter level was 1.9% on Eutric Gleysols under broken forest. Under elephant grass of previously cultivated fields, organic matter content of 1.1% was recorded on a sandy clay loam Ferric lixisol. On the same soil under cassava and tobacco in the same location, organic matter content was 1% and 0.81%, respectively. Cassava and tobacco were often grown as continuous monocrops leading to the marked depression in the soil organic matter. As shown in Table 2, organic matter content in the Guinea and Sudan savanna zones of Ghana is generally low with a mean around 1% in cultivated fields (Adu, 1969, 1975, Fosu et al., 2004). Continuous cropping and high temperatures are considered the main contributors to the low organic matter content. The Guinea and Sudan savannas of Ghana have monomodal rainfall with long and severe dry season that exposes the sparse grass vegetation and any remaining crop residues to annual bushfires and overgrazing. As a result annual contribution of native vegetation and crop residue to soil organic matter is low (Lal, 1987). About 94% - 98% loss in organic carbon and nitrogen were observed when vegetation was subjected to bushfires (Mackensen et al., 1996, Bagamsah, 2005). Since organic matter is the main determinant of inherent soil fertility, the soils of Guinea and Sudan savannas are poor soils. In studies conducted by Senaya et al., (2001) in the Kumawuri Valley in the Northern Region of Ghana covering an area of about 500 ha, the average topsoil organic matter level was 1.2-1.3%. The subsoil organic matter level had an average value of 0.9%. Fosu (2005) in a similar study of 600 ha in the Navrongo (Sudan savanna) area of Upper East Region of Ghana found organic matter content of 0.64 – 1.4% in the top soil. Agyare (2004) characterized soils of the Tamale area (Guinea savanna) and found organic carbon content of 0.35 – 1.03% in the top soils of 9 soil series encountered. In another study conducted in the Sillum Valley in the northern region of Ghana, Dedzoe et al. (2002) found the soil organic matter content to range from 0.4 to 1.1% in the topsoil and 0.4 to 0.7% in the subsoil. Organic matter content of soils in the Kulda – Yarong valley of the northern region of Ghana were found to range from 1.1 to 1.9% in the topsoil and about 0.5 to 0.9% in the subsoil (Dedzoe et al., 2002). These values are averages of upper slope to valley bottom soils. Work done by Dedzoe and Tetteh (2003) in the oil palm plantation estates of the Central Region of Ghana showed that organic matter content of soils ranged from 2.5 to 2.8% in the natural forest and from 1.50 to 2.70% in the oil palm plantation of various ages. Subsoil organic matter levels were low in both the natural forest and the oil palm plantations.

Table 2: Some of the major agricultural soils of the Guinea and Sudan Savanna zones of Ghana and their organic matter content

Soil series	Classification	Location	Agro-ecology	Depth (cm)	SOM (%)
Varempere	Ferric Luvisol	Lawra	Sudan savanna	0-8	0.48
Kolingu	Chromic Luvisol	Wa-Sawla region	Guinea savanna	0-5	0.72
Nakori	Ferric Lixisol	Lawra-Wa region	Guinea savanna	0-8	3.59
Bianya	Eutric Plinthosol	Lawra	Sudan savanna	0-10	0.65
Siare	Eutric Fluvisol	Bolga-Bawku road	Sudan savanna	0-5	0.88
Lima	Eutric Gleysol	Nasia	Guinea savanna	0-10	0.95
Kpelsawgu	Eutric Plinthosol	Tamale-Bolga road	Guinea savanna	0-10	1.86
Lumo	Eutric Plinthosol	Bongo Da	Sudan savanna	0-13	1.25
Sanda	Gleyic Lixisol	Yendi-Nakpanduri road	Guinea savanna	0-13	0.83
Dagare	Dystric Fluvisol	Kokobila	Sudan savanna	0-5	0.40
Damongo	Dystric Nitosol	Damongo	Guinea savanna	0-8	1.13
Puga	Eutric Plinthosol	Tono	Sudan savanna	0-8	0.54
Tanchera	Sodi-Haplic Luvisol	Tono	Sudan savanna	0-8	0.85
Pu	Eutric Regosol	Navrongo	Sudan savanna	0-11	0.96
Pusiga	Eutric Leptosol	Pusiga	Sudan savanna	0-7	0.79
Bianya	Haplic Lixisol	Nangodi	Sudan savanna	0-10	1.05

Source: S.V. Adu (1969, 1995a, 1995b, 1996)

Changes in soil organic matter in some soils of Ghana

Soil organic matter accumulation under tree plantations in the semi-deciduous forest zone of Ghana was monitored by Tetteh (1997). Soil organic matter content under *Gmelina aborea* in the 0-15 cm layer increased from 3.8 to 6.4% in seven years (1990 - 1997). During the same period, SOM increased under *Tectonia grandis* (Teak) from 2.7% to 3.6%. The increase under cocoa was 3.1% to 3.6%. Though the highest organic matter increase of 68.4% occurred under *Gmelina aborea,* the highest leaf litter accumulation of 15 t ha^{-1} was obtained under Teak. Leaf litter accumulation was in the order: Teak >Cocoa>*G. aborea*. The ratio of the amount of undecomposed litter and total litter fall was computed as the isohumic coefficient (*f*). The values were 0.21, 0.65 and 0.73 for *G. aborea*, Cocoa and Teak, respectively (SRI, 1997). This indicates that more litter decomposed under *G. aborea* and was added to the soil organic matter than the other two species.

Decline of soil organic matter under maize with slash/burn, slash/no burning and herbicide use was monitored for four years in the deciduous forest region of Ghana (SRI, 1998). Soil organic matter declined from 4.5% to 1.9% with slash and burn within the period, which was the highest decline. For the same period, the decline was 4.5% to 2.3% and 4.5% to 2.6% with slash/no burning and herbicide use, respectively.

In Northern Ghana where compound farming is a common practice, wide variations have been found in soil organic matter between the compound farms that received household waste and animal manure and bush farms that were not manured (Table 3). The organic matter content of compound farms ranged from 2.6 – 5.0% while that of bush farms ranged from 0.7 – 0.36%. Differences in organic matter up to 900% were recorded on farmers' field between compound and bush farms (Korem, 1996). Both fields were under continuous cereal for several years.

Table 3: Organic matter in the 0 – 10 cm depth of soils on compound and bush farms in Bawku District of Upper East Region of Ghana

Farmer	Soil Organic matter content		Distance of bush farm from compound farm
	Compound Farm	Bush farm	
Sumaila Widana	2.6	0.57	200 m
Ndago Asaki	4.8	0.7	250 m
Anane Abugri	3.3	0.36	30 m

Source: Korem, 1996

Cultivation has been shown to be an important driving force for SOM depletion. Soil organic matter in an uncultivated sacred grove was 900% higher than that in a nearby cultivated field (Table 4).

Table 4: Soil organic matter content in and outside a sacred grove near Tamale

Location	Organic matter (%)	
	Depth 0 – 10 cm	Depth10 – 25 cm
Sacred grove	13.1	7.1
Okro farm 5 m outside sacred grove	1.5	2.1
Cassava farm 12 m outside grove	1.4	1.6

Source: Korem (1996)

Organic matter is very closely associated with soil nutrients. It is the main source of the soil's reserve of nitrogen and an important source of its phosphorus and sulphur. In the tropics such as in Ghana, the fertility reserves of the soil are largely associated with its organic matter content. Since the average nitrogen content of the soil organic matter is about 5 percent, a measure of soil organic matter content gives an indication of the nitrogen status of the soil as well as the quantity of nitrogen that may be released to growing crops.

Soil Nitrogen

Nitrogen is very important for plant growth as it is required for protein synthesis. It is required in greater amount than all other nutrients and its deficiency results in stunted growth. In general soil nitrogen is higher in forest soils than in savanna soils in Ghana. Total nitrogen in forest soils range between 0.1 to 0.6% but that of savanna soils is usually between 0.02 to 0.07%. However, intensively cropped fields in the forest zone can have total nitrogen levels as low as 0.06%. Forest soils in Ghana generally contain about 7000 kg nitrogen and savanna soils 1700 kg nitrogen per hectare in the 0 – 30 cm layer.

Most of the nitrogen in soils is in organic form. The organic nitrogen is slowly mineralized by bacteria to the inorganic ammonium and nitrate forms which can be taken up by plants, and it is the level of these that immediately concerns crop growth. According to Nye and Stephens (1965) analyses of the long term fertilizer trials sites in Ghana revealed that the rate of mineralization of organic nitrogen in the 0-30 cm layer is about 3 per cent of the total per annum in forest and 4 per cent in savanna soils. Thus forest soils receive up to 200 kg available nitrogen and savanna soils up to 70 kg per hectare per annum by mineralization.

Some amount of soil nitrogen in the form of NH_4+ is fixed in the inter-layers of clay minerals as in soils with vertic properties (Akuse, Agawtaw, Lupo series) but the occurrence of this in Ghanaian soils is low as the smectites responsible for fixation are low in the soils.

In a study carried out in Ghana by Greenland (1958) on the variations in the amount of NH_4^+ and NO_3^--N during the year he observed two peaks for southern Ghana, i.e. July-September and March-April. The peak values were between 20 and 30 ppm NO_3 –N. Ammonium levels were however higher in soil under 20-year forest fallow than in the continuously cropped forest soils. During the dry season there is a gradual increase in the level of nitrate and a more rapid increase as soon as the rains begin. The levels fall after a few weeks and remain low until the following dry season. In northern Ghana which is mainly savanna vegetation, there is only one dry season and only one peak during the year. There is usually a rapid rise in the nitrate level during the dry season due to mineralization of organic nitrogen and no loss by leaching of the nitrate formed. There is a rapid rise also at the beginning of the rains that may be explained by the partial sterilizing effect of the dry season, conversion of the organic matter during the dry season into a form that is readily mineralizable and the stimulation of the mineralizing bacteria by the early rains. There is however a rapid fall in the nitrate level shortly after the start of the rains due largely to the leaching that occurs once sufficient rain has fallen to saturate the soil, partly to absorption by the growing vegetation and microorganism, and to denitrification as most of the soils temporally impound water as a result of underlying hard pan. Under natural savanna the total nitrogen may be high in soils undisturbed for generations, as in fetish groves. However, in the open savannas subjected to annual bushfires and intense cultivation, soil nitrogen remains very low. Nitrogen is the most limiting nutrient in savanna soils of Ghana. Most cereals cannot grow well without soil amendment with the nutrient.

Under forest vegetation, on the other hand, the average level of N is appreciable and nitrate leaching is intense. There is usually a sharp downward trend of nitrate level during the rainy seasons indicating considerable losses by leaching and possibly by denitrification; yet in spite of these loses, land rested under forest has relatively high total nitrogen content. It follows that there must be a rapid turnover of nitrogen in the forest soil, both gains and losses being considerable (Greenland, 1958). Planting at the beginning of the rains coincides with the flush of soil nitrate, so that crops do not suffer a marked nitrogen deficiency at this time in the forest zone. Generally in the forest zones of Ghana there is no deficiency of nitrogen for the first few years after clearing as exemplified in the lush growth of cereals particularly maize. In the Guinea savanna, cereals are short of available nitrogen, especially after the first two years following a long period (ten years) under natural grass fallow (Nye, 1950).

Distribution of soil nitrogen in Ghanaian soils

Savanna soils

Studies conducted in the Sillum Valley of the northern region (woody savanna) of Ghana show that soil total nitrogen content in the upland and lowlands ranged from 0.06 to 0.14% in the topsoil and 0.01 to 0.07% in the subsoil (Dedzoe et al. 2001). Dedzoe et al., (2002) characterized soils in the Kulda – Yarong Valley in the northern region of Ghana (grass savanna) and found soil total nitrogen levels to range from 0.06 to 0.08% in the topsoil and 0.03 to 0.04% in the subsoil. Senaya et al. (2001) also characterized soils in the Kulawuri valley comprising upland and lowland soils. They found total nitrogen levels to range from 0.07 to 0.10% in the topsoil and 0.04 to 0.07% in the subsoil. In the study conducted by Fosu (2005) in the Navrongo area (Sudan savanna), total nitrogen levels ranged from 0.05 to 0.08% in the top soil and 0.03 -0.04% in the sub soil. Adu (1969) in a survey covering the Navrongo-Bawku area of the Sudan savanna zone of Ghana reported total N content of the soils to range from 0.02 to 0.17% in the top soil. For most of these soils, it is not possible to obtain a good yield of cereals without soil amendments. Cereals such as millet, sorghum and maize are therefore either grown on compound farms that are manured regularly or on bush farms that receive some amount of compost or mineral fertilizer. Compound farming which is practiced in the Guinea savanna is the system where the areas surrounding homesteads are intensively cultivated and soil fertility under continuous cropping over decades has been maintained by applying crop residues, household refuse and animal manure. The practice has resulted in the build up of organic matter (Table 3) and increase in soil fertility under continuous cropping and yields from these fields (3 t maize grain yield per ha) are much higher than on ‘distant or bush farms’ (0.5 to 1.0 t per ha; Abunyewa et al. 1998).

Forest soils

Total N content of soils of the forest zones of Ghana are considerably higher than in the savanna zone. Values reported range from 0.1 to 0.5%. In a study conducted by Tetteh et al. (2004) at the oil palm plantation estates at the forest zone of the western region of Ghana, it was established that total nitrogen levels ranged from 0.20 to 0.50% in the topsoil. These levels could be described as from moderate to high. These levels decreased to a range of 0.10 to 0.28% in the subsoil. Tetteh and Dedzoe (2004), in a similar study of soils in the forest zone of the Western region of Ghana found total nitrogen content of soils to range from 0.2 to 0.5% in the topsoil. Subsoil total nitrogen content ranged from 0.10 to 0.18%.

In the coastal thicket of the Central region of Ghana, studies conducted by Dedzoe and Tetteh (2003) indicated that soil total nitrogen levels ranged from 0.10-0.24% in the natural forest but low in the soils of the nearby oil palm plantations. In forest soils the decline of total N with soil depth is much lower than with SOM (Fig. 1). Felling of the forest for the cultivation of food crops could lead to an initial build up of higher soil organic matter and total nitrogen in the first year followed by gradual decline in subsequent years. Boi series planted to cassava and plantain (C & P) had a higher total nitrogen level than the Secondary forest (2^{o} Frt, Fig. 1) due probably to the high release of nitrogen from decomposing biomass in the early years of cultivation. This was not apparent in the Bremang series. In the pineapple growing area of Bawjiase and its surroundings the soils are light textured. With continuous ploughing and harrowing of the soils and continuous cultivation of pineapples, soil organic matter and nitrogen contents of soils were found to be low as compared to the surrounding forest vegetation (Table 5).

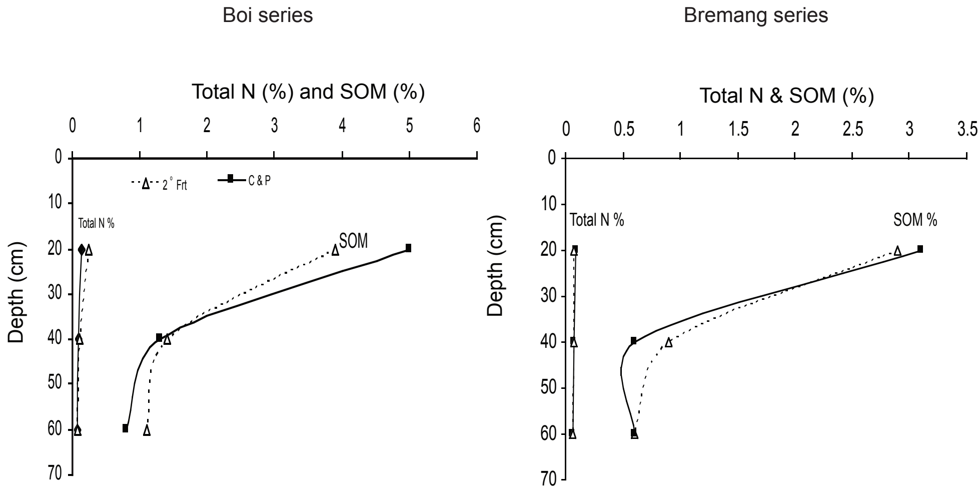

Figure 1: SOM and Total N distribution in some forest soils of Ghana. 2° Frt = Secondary Forest; C&P = Cassava and Plantain

Table 5. Soil organic matter and total nitrogen content of pineapple growing soils at Bawjiase, Ghana

Parameter	Uplands		Lowlands	
	Range	Mean	Range	Mean
Total Nitrogen %	0.09 - 0.33	0.19	0.10 - 0.15	0.12
Organic Matter %	0.70 - 2.60	1.4	0.80 -1.2	0.98
Nearby forest				
Total Nitrogen %	-	0.33	-	-
Organic matter %	-	2.50	-	-

Management of Organic matter and nitrogen in soils of Ghana

Quansah et al. (2001) evaluated farmers' perception and management of organic matter in 155 communities covering parts of the forest and savanna zones of Ghana. Their findings revealed that farmers are well aware of organic matter and its important role in soil fertility and increased crop yields. In the forest areas farmers perceive soil organic matter generally by its dark colour while in the savanna areas farmers perceive a soil as having organic matter mostly by how dense the soil is and the kind of vegetation it supports. Farmers in all agro-ecologies perceive organic matter as primary provider of plant nutrients and its ability to improve soil aeration, drainage, loosening of the soil and ability to conserve water.

Traditional practices depend on fallowing to restore organic matter and nitrogen in the soils of Ghana. Nye and Stephens (1962) stated 5-10 years of fallow and a cropping period of 1-3 years as necessary for maintaining soil fertility in northern Ghana. Fallowing is no longer an option due to increasing pressure on land for farming and other uses. One year fallow with leguminous cover crops have been reported to improve soil fertility and increased crop yields mainly through increased supply of nitrogen. An increase in SOM of 1.5-9.1% and total N of 2.1-13.7% was obtained with four cover crops and mineral fertilizer in a 1-year fallow management experiment on Ferric lixisols in the Guinea savanna zone of Ghana (Fosu et al. 2003). Kombiok et al. (1995) reported increase of soil total N from 0.059 to 0.07% with 2-year Calopogonium fallow.

Legumes can contribute nutrients particularly N (and organic matter) to the farming system through legume/cereal rotation, intercropping, alley cropping and herbaceous leguminous fallow systems. Application of animal manure and household refuse has sustained production in the intensively cropped fields of the Upper Regions of Ghana. Organic matter levels in order of magnitude 10 times higher have been obtained on compound farms that received manure every year compared with bush farms that were not manured (Table 3). Anane-Sakyi and Dzomeku (1998) in an evaluation of indigenous soil fertility maintenance practices in northern Ghana reported that 83% of farmers interviewed use manure as key soil fertility management practice. The major strategies farmers use in maintaining or augmenting SOM apart from manure application include mulching with crop residues, slashing weeds without burning, composting and natural fallowing (Quansah et al. 2001). Very few farmers use promoted technologies such as green manuring, cover cropping, minimum tillage and agroforestry (Quansah et al. 2001).

Conclusion

The amount of soil organic matter in soils of Ghana varies widely depending on the agro-ecology, soil type, drainage, land use and management systems. Generally the amount of SOM in the savanna soils is lower than those in the transition and forest soils. While forest soils in Ghana have mean SOM of about 4% in uncultivated fields, the SOM in savanna soils is usually ≤ 1%. Cultivation has been shown to depress SOM up to 500% in both forest and savanna soils. In the savanna areas of northern Ghana, soil organic matter is maintained with farm yard manure and household refuse at about 3% on compound farms compared with a mean of about 0.5% on bush farms about 200 m from the homestead. This accounts for the higher yields on compound farms despite the fact that they are intensively cropped to cereals with little crop rotation. Since SOM is the main supplier of native N, total soil nitrogen is higher in forest soils than in savanna soils. While forest soils receive about 200 kg available N per hectare per annum, savanna soils receive less than 70 kg per ha per year. For most forest soils in Ghana, it is possible to obtain a good yield of cereal without any soil amendment particularly if the soil has not been cultivated for more than 5 years. Savanna soils however need soil amendment in almost all cases to obtain good yield of cereals. Cultivation has the same effect of reducing total soil N as it does for SOM. Farmers in Ghana consider SOM as primary provider of plant nutrients. In order to maintain or increase soil organic matter in soils of Ghana, conservation tillage with cover crops, use of crop residues and farm yard manure need to be encouraged. Increased use of mineral fertilizer will also help to maintain soil organic matter and soil nitrogen through increased contribution of below ground biomass obtained from larger crops produced as a result of good plant nutrition.

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Chapter 5

Influence du mode de gestion de la fertilité des sols sur l'évolution de la matière organique et de l'azote dans les zones agro écologiques du Burkina Faso

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Résumé

La variabilité pédoclimatique du Burkina Faso permet une diversification de la production agricole. Les pratiques de fertilisation varient et beaucoup ne sont malheureusement pas toujours adaptées pour une meilleure gestion de la fertilité de ces sols. On assiste en conséquence à une baisse de la teneur en matière organique des sols ainsi que l'azote, facteurs premiers dans la productivité d'un sol. Des travaux de recherches ont porté sur l'influence des divers modes de gestion des terres et de pratiques culturales sur l'évolution du statut organique et azoté des sols sous cultures à travers les principales zones agro écologiques du Burkina Faso et ceux dès la mise en valeur des jachères. Les résultats de ces déférents travaux montrent que (i) en absence de toute restitution, les teneurs en matière organique baissent de l'ordre de 2% par an en moyenne, (ii) l'emploi d'engrais azoté seuls stimule la baisse du taux de matière organique par une augmentation de la minéralisation et, les pertes en matière organique dans ces conditions passent de 2 à 2,8%. par an, (iii) la restitution seule ne suffit pas pour relever le niveau de matière organique du sol et (vi) l'emploi combiné des pailles et de l'azote permettait d'augmenter le stock d'azote organique du sol. Après la mise en culture, l'horizon 0-10 est celui qui est le plus affecté par les différents processus et les variations des stocks organiques concernent surtout les 40 premiers cm du sol sous culture. En conclusion on retiendra que (i) la mise en culture des jachères s'accompagnait toujours par une baisse plus ou moins rapide des teneurs en matière organique et en azote, (ii) la fumure organo-minérale semble assurer une certaine stabilité du taux de carbone à court terme (apports annuels), (iii), de fortes doses de fumure organique (de l'ordre de 40 tonnes ha_{-1} an_{-1}) sont requises pour augmenter les taux de matière organique du sol.

Mots clés: *Pratiques agricoles, gestion de la fertilité de sols, matière organique, azote, zone agro écologique, Burkina Faso.*

Abstract

The climates and soils variability of Burkina Faso made a diversification of the agricultural production. The fertilization practices vary and much are not unfortunately always adapted for a better soils fertility management. Consequently one attends a decrease of the soils organic matter content as well as nitrogen. Researches was done about the influence of the various soil fertility management and practices on the evolution of the organic and nitrogen statute of soils under crops through the main agro ecological zones of Burkina Faso and those since the enhancement of the fallows. The results of these deferential works show that (i) in absence of all restitution, the soil organic matter contents is lower than an average of 2% per year, (ii) the use of nitrogenous fertilizers only stimulates the decrease of the organic matter rate by an increase of the mineralization and, the losses in organic matter in these conditions pass from 2 to 2,8%. per year, (iii) the restitution only is not sufficient to raise the level of soil organic matter and (vi) the use combined of straws and nitrogen permitted to increase the stock of soil organic nitrogen. After the setting in culture, the horizon 0-10 cm is the one that is the most affected by the different processes and the variations of the organic stocks concern the first 40 cm of soil especially under crops. In conclusion one will keep that (i) the setting in cultivation of the fallows always came by a decrease more or less fast of the organic matter contents and also for nitrogen, (ii) the organo-mineral fertilizer seems to assure a certain short-term stability of the carbon rate (yearly contributions), (iii), strong doses of organic manure (about 40 tons ha^{-1} year^{-1}) are required to increase the rates of soil organic matter.

Keywords: *agricultural practices, soils fertility management, organic matter, nitrogen, agro ecological zone, Burkina Faso.*

Introduction

Le Burkina Faso, pays sahélien situé dans la boucle du Niger, a une économie basé essentiellement sur les productions agricoles. La variabilité pédo-climatique du pays permet une diversification de la production agricole. En effet du nord au Sud la variabilité du niveau pluviométrique ainsi que la qualité des sols permet de percevoir une multitude de cultures passant des céréales aux Oléagineux et légumineuse à graines ainsi qu'au coton dans les zones plus arrosées. On remarque également que les pratiques de fertilisation sont variables selon le milieu. Il existe encore dans s du nord et de l'ouest la pratique des jachères de courte durée tandis que dans d'autre à forte densité de population c'est une agriculture de type minière sur des sols devenus très pauvres. Beaucoup de ces pratiques ne sont malheureusement pas adaptées pour une meilleures gestion de la fertilité de ces sols et entraînement de fait une baisse de la teneur en matière organique des sols ainsi que l'azote facteurs premiers dans la productivité d'un sol.

Des recherches sont conduite depuis de longue date sur la fertilité des sols en partant de la jachère, de l'influence de la proximité des ménages sur la fertilité de champs à l'influence des modes de fertilisation sur ces sols. Ce chapitre se veut de faire le point de ces travaux afin de situer les exploitants sur les effets de leurs pratiques sur la qualité du sols et sa productivité de façon à assurer une gestion durable de la ressource sol qui est de plus en plus rare. Cette synthèse de travaux antérieurs sur la gestion de la fertilité des sols au Burkina Faso présente la situation de la l'évolution de la matière organique du sol des jachère dès leur mise en valeur comme situation référentielle de l'évolution du niveau de fertilité des sols au Burkina faso. Elle présente également l'influence de la proximité des ménages sur le niveau de fertilité organique et azoté des sols car cette proximité est un facteur favorable aux apports de fertilisants extérieur ; Enfin une synthèse générale est faite sur l'influence des divers mode de gestion des terres et de pratiques culturales sur l'évolution du statut organique et azoté des sols sous cultures à travers les principales zones agro écologiques du Burkina faso.

Influence de la mise en culture des jachères sur la dynamique de la matière organique et de l'azote dans les sols.

Au Burkina Faso la pluviométrie varie de moins de 400mm au nord à plus de 1200 mm au Sud et Sud Ouest. Les sols aussi sont diversifiés mais pas forcement selon cet ordre. L'essentiel des études capitalisées dans ce chapitre porte sur la mise en valeur des jachères dans les zones majeures qui sont reparties selon le niveau annuel de la pluviométrie. Il reste bien entendu que la zone plus au nord est sahélienne et la majeure partie des sols sont constitués de sables si bien que très peu d'études agronomiques sont faites la dessus. On 'intéressent alors aux plus pluvieuses.

A Saria dans la zone nord soudanienne (800 mm de pluie par an), selon les études de Sedogo (1993), sous jachère, les teneurs en matière organique les plus élevées sont obtenues sur les 10 premiers centimètres du sol. Les modifications dues à la mise en culture homogénéisent les deux horizons et a pour cause le labour annuel. Les baisses ou les augmentations de la teneur en matière organique affectent effectivement ces horizons de la même façon. Par contre à la mise en culture de ces sols on observe une baisse continue lorsqu'il n'y a pas d'apport extérieur. Au bout d'une trentaine d'années d'exploitation on semble atteindre un état d'équilibre avec 0,23%. de carbone dans le sol.

Toujours selon le même auteur, en comparant l'état du sol après 9 ans de culture à celui du sol sous jachère, on constate que la mise en culture avec application des différentes fumures induit une différenciation dans les teneurs en matière organique du profil des 40 premiers centimètres Il a par ailleurs été montré sur des sols de type ferrugineux tropicaux lessivés (luvisol) que la culture continue avec exportation des résidus de culture est incompatible avec l'intensification (Sedogo,1981). Ces études on permis de constater un appauvrissement des sols en carbone et en azote dû à la minéralisation très intense de la matière organique du sol et à un bilan humique déficitaire. En comparant les différentes fractions de l'azote organique. Le même auteur conclut à une baisse de la capacité minéralisatrice et à un état d'épuisement du sol exprimée par la forte proportion d'azote ammoniacale (NHD) mesurée. La fraction aminée de l'azote (NHND) qui est le siège des processus de minéralisation et de réorganisation, diminue tout avec la mise en culture de la jachère tout comme la matière organique du sol.

A Farako-bâ, (1100 mm de pluie, sols faiblement ferralitiques), les travaux de Hien (1990) ont montré que le taux annuel de perte de matière organique est élevé dans certains cas. En effet il a rencontré quelque fois une évolution rapide de 2% à 6% par due à l'intensification agricole des culture : elle a entraîné une accélération des phénomènes d'érosion et une minéralisation importante. En ce qui concerne les fractions de l'azote organique, il considère que la fraction aminée (NHND), de nature biologique, est dépendante des techniques culturales, alors que la fraction ammoniacale (NHD) (composée d'acides fulviques et humiques) est une propriété intrinsèque du sol (en liaison étroite avec la CEC et le taux d'argile) et évolue très peu en fonction des techniques culturales.

A Nazinon dans la zone soudanienne (1200 mm de pluie par an) les observations de Nacro et al, (2000) dans des jachères d'age différents indiquent que le stock en carbone augmente quasi régulièrement jusqu'à 30 ans sous une jachère à domination d'espèces ligneuses. Ces auteurs ont observé ensuite qu'après 40 ans de jachère avec domination d'espèces ligneuses et d'herbacées annuelles, le stock de matière organique baisse. Par ailleurs ils ont montré que les teneurs en carbone organique varient selon la taille des fractions granulométriques quelque soit l'âge de la jachère. En effets leurs résultats montrent des teneurs élevées dans les fractions fines (14267 à 20161 µg C/g fraction) et faibles dans les fractions grossières (1014 à 5369 µg C/g fraction). Ils pensent que cela indique qu'il y'a eu au cours des successions végétales post culturales une dégradation intense des litières qui aurait entraînée un fort déstockage de la matière organique des fractions grossières au profit des fractions fines du sol.

A Boundoukuy, situé en zone sud soudanienne comprise entre les isoyètes 900 et 1300 mm, les jachères de courte durée (5 à 6 ans) ont un effet positif dans la remontée du niveau de carbone et de l'azote total des sols sur les horizons de surface 0-10 cm et la jachère de longue durée permet une nette amélioration de 75% de carbone et 72% d'azote (Bilgo, 2005). Cet auteur explique ceci par le fait que les jachères réduisent les phénomènes de ruissellement et d'érosion. Selon le même auteur, la phase jachère est caractérisée par une remontée du carbone organique et des différents éléments minéraux du sol tandis que la culture continue se traduit par un appauvrissement progressif du sol. Toujours dans la même étude Bilgo (2005) montre que l'augmentation du C total et de N total dans les jachères est liée essentiellement à l'augmentation des quantités de carbone et d'azote contenus dans les fractions les plus fines (0-20 µm) quelle que soit le type de jachère (1) naturelle ou à (2) *Andropogon gayanus*. Son étude a permis de conclure que la jachère à *Andropogon gayanus* comparée au champ permanent entraîne une amélioration plus rapide du statut organique du sol et est de ce fait une alternative pour pallier la réduction du temps de mis en jachère.

En conclusion, il ressort de ces différentes études que les jachères jadis bien pratiqué en Afrique tropicaux peuvent être effectivement une bonne pratique pour une gestion durable des terres. En effets les études ci-dessus ont montré que les teneurs en matière organique et en azote des sols s'amélioraient avec le temps de mis en défends pour toutes les zones agro écologiques majeures. Le seul problème reste la pression foncière des populations qui ne permet plus d'avoir les jachères de longue durée.

Ces études ont également montré que la mise en culture de ces jachères s'accompagnait toujours par une baisse plus ou moins rapides des teneurs en matière organique et en azote indicateurs principaux du niveau de productivité des terres agricoles. Cette situation nous conduit à examiner les travaux d'autres auteurs sur les impacts de ces mises en cultures sur le statut organique et azoté des sols au Burkina Faso.

Influence des modes de gestion de la fertilité des sols sur leur statut organique et azoté

Inventaires des principales pratiques de gestion de la fertilité des sols au Burkina Faso

Au Burkina Faso, les céréales sont les plus cultivées car elles constituent la base de l'alimentation des Burkinabés. La daba et la charrue sont les outils les plus utilisés par les paysans faute de moyens financiers pour l'achat de matériel motorisé (tracteur par exemple). Les céréales telles que le mil et le sorgho sont surtout cultivées dans la zone centre, le maïs fait surtout objet de culture dans les champs de case. Au nord il s'agit essentiellement du mil. Au sud et à l'ouest le maïs est beaucoup plus cultivé car les conditions pédo-climatiques sont plus favorables. Plus au sud la production de tubercules (igname et patate douce) est assez importante et est même sources de dégradation des sols car fortement consommatrice de matière organique. Sur toutes ces cultures le travail du sol est fait à la daba (manuel) et cela ne permet pas une bonne amélioration du niveau de fertilité des sols.

On note ces dernières années une extension de la culture cotonnière qui passe de la zone ouest (zone dite cotonnière qui fournie la quasi-totalité du coton Burkinabè) à l'ensemble des régions (sauf dans le Sahel). En ce moment une concurrence en terre s'installe entre cultures cotonnières et cultures céréalières.

La jachère est une technique traditionnelle de la régénération de la fertilité du sol dont la pratique est de plus en plus compromise par une forte demande en terres cultivables suite à une forte pression démographique.

La concurrence entre l'agriculture et l'élevage et la faible intégration de ces deux activités limitent souvent la restitution des résidus de cultures et l'utilisation du fumier pour l'amélioration ou le maintien de la fertilité du sol, d'où une exportation quasi générale des résidus de récolte pour l'alimentation du bétail.

Selon Sedogo (1993) il y a une différenciation nette entre 3 systèmes dans les exploitation traditionnelles pouvant se résumer comme suit :

A : Système de culture continue dans des anciennes parcelles sans jachère avec des apports fréquents de diverses sources de matière organique.

B : Système de culture continue dans des anciennes parcelles sans jachère, sans apports organiques. Ces cas sont malheureusement les plus fréquents.

C : Système dans des parcelles de mise en culture récente. Ces cas sont assez rares, l'âge de mise en culture varie entre 4 et 11 ans.

La proximité des menages induit un mode de gestion de la fertilité des sols qui amène une différenciation dans la typologie des champs au Burkina Faso. On note 3 types de champs qui sont fonction de la distance par rapport à l'habitation et donc à l'investissement sur la fertilité des sols : (1) les champs de case (plus proches des habitations et quelques fois autour des concessions) sont les plus fertilisés. En effets ces champs reçoivent les ordures ménagères, les excréta des membres du ménage qui le plus souvent sont sans latrine, ainsi que les déjections animales en libre pâture ; (2) les champs intermédiaires moins bien fertilisés et (3) les champs de brousse qui le plus souvent bénéficient de très peut d'apports extérieurs de fertilisants organique et / ou minéral. Les investigations faites par Sedogo (1981) ont montré effectivement une différenciation entre ces types de champs au niveau de leur fertilité chimique comme ont le voit dans le tableau 1.

Tableau 1: Influence de la proximité des ménages sur la qualité physico-chimique des sols

	C. Total %	N Total %	Complexe adsorbant en me/100 g				
			CEC	Ca^{++}	Mg^{++}	K^{+}	pH eau
Champs de cases	1,1-2,2	0,95-1,75	4,2-12	2,25-10,25	1,3-5,15	0,45-2,35	6,7-8,25
Champs intermédiaires	0,50-0,95	0,55-0,85	3-4,2	1,30-1,60	0,85-1,30	0,40-1,10	5,75-7
Champs de brousse	0,24-0,43	0,23-0,45	2,4-3	0,85-1,30	0,25-0,85	0,06-0,13	5,75-6,2

Source : Sedogo, 1981

On note en conclusion que ces principales pratiques de gestion de la fertilité des sols ont certainement des effets diversifiés sur leur statut organique et minéral. Les paragraphes suivants font le point des résultat de recherches conduites à cet effets soit en station de recherches, soit en milieu paysan.

Influence de la gestion de la fertilité des sols cultivés sur la dynamique de la matière organique et de l'azote.

Effets des systèmes de culture sur la dynamique de la matière organique du sol

Dans les essais longue durée en zone cotonnière de Hien (1990) (15 années, 5 cycles cotonnier-sorgho-arachide), tous situés sur des sols ferrugineux tropicaux, l'évolution de la teneur en carbone et du taux de perte annuelle en matière organique sont très caractéristiques: de 2 à 3% par an durant les premiers cycles, ce taux passe à 15% par an par la suite. Dans les derniers cycles, on assiste à une stabilisation de la teneur en carbone du sol à des valeurs très faibles. Bien qu'elle n'ait pas fait l'objet de mesures, l'érosion semble être une cause de cette évolution. ..

Sous monoculture de sorgho en sol ferrugineux tropical (zone centre Saria), trois fractions granulométriques ont été séparées à partir d'échantillons de l'horizon 0-20 cm (Kambiré, 1991). La fraction comprise entre 200 et 2000 µm correspond à un mélange de débris végétaux grossiers et de sables grossiers qui sont constitués en majeure partie par des grains de quartz. La fraction comprise entre 50 et 200 µm composée de débris végétaux fins, fortement humifiés et de sables fins. La fraction organo-minérale de taille inférieure à 50 µm est composée de débris végétaux très fins, de limons grossiers, de débris microbiens, des produits limono-humiques. Elle correspond à une phase d'humification plus poussée que la précédente.

Effets des fumures sur la dynamique de la matière organique et de l'azote du sol

La fertilisation des cultures au Burkina Faso a jadis été mise en route par les structures de recherches française et sur des cultures qui avaient un intérêt pour les industries et les besoins coloniaux. C'est ainsi que la fertilisation minérale a été adoptées avec la mise au point et l'utilisation de formules d'engrais purement chimiques comprenant un complexe NPKSB et urée adaptées au cotonnier et aux céréales. Cette formule a fait l'objet d'utilisation intensive qui malheureusement cause des problèmes d'ordre économique car non accessible par son coût, et surtout techniques car acidifie à long terme le sols par la lébération de l'aluminium échangeable (Guira, 1988). En effet dans la zone centre (900mm de pluie par an) la fertilisation minérale a acidifié les sols et accrut les pertes en N. En revanche cette situation à conduit la recherche à trouver des solutions correctives et c'est ainsi que la chaux agricole fut testée. En effet à Saria, zone centre, le chaulage a eu un effet positif sur la remontée du N total du sol (Sedogo, 1993). Cependant, il montre aussi que le chaulage n'agit que sur les 20 à 30 premiers cm du profil et que son action est limitée dans le temps (6 à 8 ans).

Cependant, le chaulage ou l'apport de matière organique comme le fumier permet de stopper la dégradation du sol et les pertes d'éléments nutritifs et de restaurer la fertilité du sol mais en revanche, ces deux pratiques conjuguées activent la dégradation de la fertilité azoté du sol et accroissent les pertes jusqu'à près de 70

$KgNha^{-1}an^{-1}$ vraisemblablement par dénitrification et dans une moindre mesure par volatilisation et lixiviation (Bonzi, 2002).

Toujours pour la zone centre (Saria), avec les apports massifs de l'ordre de 40 tonnes de fumier à l'hectare tous les 2 ans, dose malheureusement incompatible avec les disponibilités des exploitations, on assiste à une augmentation du taux de carbone dans le sol (Sedogo, 1993). La combinaison fumure minérale et fumier permettent une stabilisation de la perte en carbone même après 18 années de cultures. En absence de fumure azotée associée, il y a une baisse globale du stock organique du sol de 17% ce qui fait une perte moyenne annuelle de l'ordre de 2% Elle est de 2,1 %. (0,25%./an) avec les apports annuels de 10t de pailles et 7,8 % (0,70% / an) avec le fumier. Le bilan semble équilibré avec les composts aérobies et positif avec les composts anaérobies (moins évolués) avec une augmentation globale de 8,5%. (environ 1 %an).

L'évolution annuelle du bilan de l'azote montre des différences entre les traitements étudiés par Sedogo (1993:

- Avec le témoin, le bilan a toujours été négatif. Ceci signifie que les exportations dépassent largement les apports (uniquement par les eaux de pluie).
- Avec la fumure minérale vulgarisée (100 kg de complexe 14-23-14-6S-1B + 50 kg ha^{-1} d'urée 46%N) le bilan théorique est déficitaire au départ et ce, pendant les 10 1ères années d'exploitation. Les apports d'azote par les engrais ne compensent pas les exportations. Les formules utilisées étaient alors déséquilibrées.
- Avec la fumure organo-minéral vulgarisée (5tonnes de fumier ha^{-1} + 100 kg de complexe 14-23-14-6S-1B + 50 kg ha^{-1} d'urée 46%N), le bilan azoté a été positif dès le départ.

En présence d'engrais azoté, la baisse en azote est plus forte en comparaison au témoin sans restitution organique et est en moyenne de 2,8% par an. A l'exception des pailles, on enregistre une tendance à la baisse avec les autres substrats. Les apports annuels de 10t de pailles donnent un bilan azoté équilibré.

En absence d'azote, la baisse de l'azote est plus importante que celle du carbone (27,3%. soit en moyenne 3% par an) pour le témoin sans apport organique. Tous les substrats organiques entraînent une augmentation de l'azote du sol. Mais cette augmentation concerne seulement les 40 premiers centimètres.

En présence d'engrais azotés, on constate la même baisse en absence de toute restitution organique. Les effets des substrats sont accrus sauf pour la paille.

Avec la fumure minérale forte seule (100 kg de complexe 14-23-14-6S-1B + 100 kg ha^{-1} d'urée 46% N), le bilan a été déficitaire pendant les 4 premières années avant de devenir positif avec le changement de la formule. Là aussi, les apports couvrent largement en théorie les besoins de la plante. La fumure organo-minérale forte (FMO) (40 tonnes de fumier ha^{-1} + 100 kg de complexe 14-23-14-6S-1B + 100 kg ha^{-1} d'urée 46% N) est celle qui donne le bilan le plus positif. Bien que faible au départ (mêmes apports que sur la fumure organo minérale faible), elle est devenue très positive après les 32 années de cultures. Théoriquement l'excédent d'azote avec cette fumure est de 6,36 kg de N ha^{-1} , ce qui doit se traduire par un enrichissement du sol en azote.

En conclusion, la différenciation entre les pratiques de fertilisation montre l'importance des apports fréquents de matière organique dans ces systèmes. Ces apports permettent d'augmenter la matière organique du sol. La non restitution entraîne au contraire un appauvrissement. Les parcelles les plus récentes se situent à un niveau intermédiaire, ce qui montre le rôle du temps de mise en culture dans les systèmes traditionnels. Les apports d'engrais chimiques entraînent aussi une baisse de stock de matière organique mais les teneurs sont plus élevées que chez le témoin.

L'utilisation des bilans apparents ne fait que renforcer les hypothèses relatives aux effets spécifiques de la matière organique et aux processus d'acidification. En effet, à l'exception du témoin, tous les traitements ont des bilans positifs en ce qui concerne l'azote. Les formules de fumure proposées semblent bien équilibrées et devraient traduire à terme un enrichissement du sol en azote. Les apports d'engrais chimiques entraînent aussi une baisse de stock de matière organique mais les teneurs sont plus élevées que chez le témoin.

Par rapport au sol sous végétation naturelle, la tendance est à la baisse pour la matière organique. Au niveau du carbone total, la baisse est continue chez le témoin. Au bout d'une trentaine d'années on semble atteindre un état d'équilibre avec 0,23 %de carbone dans le sol.

La fumure organo-minérale semble assurer une certaine stabilité du taux de carbone à court terme (apports annuels). Après cette période les teneurs semblent varier d'une année à l'autre en fonction des apports avec cependant une tendance à la baisse. Pour augmenter les taux de matière organique du sol il faudrait de fortes doses de fumure organique (de l'ordre de 40 tonnes ha^{-1} an^{-1})

Effets de la restitution de résidus de récolte et du travail du sol sur l'évolution de la matière organique et de l'azote du sol.

En station de recherche à SARIA, plusieurs études ont été conduites et ont mis en comparaison les enfouissements, le mulch, le brûlis et les exportations des résidus de récolte sur le statut organique et minéral du sol. Une synthèse de ces travaux faite par Sedogo (1993) à permis de montrer que les exportations des résidus entraînent un appauvrissement en matière organique du sol. Cela se matérialise par des teneurs plus importantes en carbone et azote organique sur les traitements mulch et enfouissement. Les effets du brûlis sont assez faibles. En arrière-effet, on a les mêmes tendances même si les teneurs en carbone sur les traitements mulch et enfouissement sont plus faibles. La minéralisation des pailles semble plus poussée dans le second cas.

La technique du brûlis, même si elle permet d'augmenter la quantité en bases échangeables du sol, en particulier en potassium, n'a pas d'effet sur la matière organique. Elle est à alors à déconseiller surtout quand on sait son effet stérilisant sur la couche superficielle du sol.

Dans le cas de la culture intensive avec labour, le brûlis peut provoquer à terme une baisse de la production et une dégradation des sols. Selon le même auteur, les caractéristiques des sols sous culture (Tableaux 2 et 3) montrent que l'enfouissement des pailles permet d'augmenter le taux de matière organique du sol. Cette augmentation est accrue en présence d'engrais azotés pour ce qui concerne le stock d'azote organique. Au niveau de l'azote organique les pertes sont plus importantes que celles du carbone. On constate cependant que l'emploi combiné des pailles et de l'azote permettait d'augmenter le stock d'azote organique du sol dans les 40 premiers centimètres du profil du sol sous culture. Après la mise en culture, l'horizon 0-10 est celui qui est le plus affecté par les différents processus.

D'une manière générale les résultats de Sedogo (1993) montrent une variation globale du stock organique du sol comme observé précédemment : baisse de 33% en absence de tout apport organique. En absence d'apport d'engrais azotés, les apports annuels de 10 t de pailles stabilisent le niveau du stock organique. Avec les autres substrats, on enregistre des pertes de l'ordre de 5%. en moyenne. Avec les engrais azotés, on constate une baisse au niveau des pailles et des composts aérobies. Par contre avec le fumier et les composts anaérobies, on enregistre une augmentation du stock organique du sol (3,5% en moyenne). Les variations observées sont donc fonction de la nature du substrat incorporé.

Des analyses ont été effectuées sur les deux séries (sorgho et coton) en 1977, soit 7 ans après la mise en culture (Tableaux 2 et 3). Rappelons que sur la série sorgho on teste les arrière-effets des modes de restitution des résidus de sorgho et sur la série coton les effets directs. L'absence de données analytiques de départ nous amène à comparer seulement les différents traitements entre eux:

a) En effet direct: on constate que les exportations des résidus entraînent un appauvrissement en matière organique du sol. Cela se matérialise par des teneurs plus importantes en carbone et azote organique sur les traitements mulch et enfouissement. Les effets du brûlis sont assez faibles.
b) En arrière-effet: on a les mêmes tendances même si les teneurs en carbone sur les traitements mulch et enfouissement sont plus faibles.

Tableau 2: Effets des modes de restitution des résidus de sorgho sur le statut chimique du sol sous culture de coton.

		C %	N %	Ca^{++}	Mg^{++}	K^{+}	SBE	CEC	
						me/100g			pHeau
Manuel	Exportation	0,40	0,37	0,66	0,24	0,09	1,00	1,86	4,80
	Brûlis	0,42	0,41	0,77	0,29	0,13	1,20	2,10	5,05
	Mulch	0,47	0,42	1,10	0,43	0,16	1,70	2,75	5,15
Labour	Exportation	0,41	0,35	0,76	0,24	0,09	1,10	2,30	4,75
	Brûlis	0,43	0,37	0,80	0,27	0,14	1,22	2,37	4,90
	Enfouissement	0,48	0,41	1,04	0,37	0,13	1,55	2,94	4,80

Tableau 3: Arrière effets des modes de restitution des résidus de sorgho sur le statut chimique du sol sous culture de sorgho

		C %	N %	Ca++ CEC	Mg++	K+	SBE		
						me/100g			pH eau
Manuel	Exportation	0,41	0,49	1,20	0,42	0,09	1,72	2,61	5,05
	Brûlis	0,40	0,45	1,02	0,38	0,11	1,52	2,56	5,00
	Mulch	0,45	0,56	1,11	0,43	0,17	1,72	2,54	5,15
Labour	Exportation	0,39	0,42	1,21	0,41	0,08	1,71	2,56	5,40
	Brûlis	0,40	0,44	1,01	0,43	0,11	1,56	2,50	5,35
	Enfouissement	0,44	0,46	1,20	0,49	0,11	1,81	2,82	5,25

L'examen de l'état du sol sous culture fait ressortir un enrichissement en matière organique avec le mulch ou l'enfouissement, de même qu'une augmentation de la CEC. Ces deux formes de recyclages jouent donc un rôle bénéfique propre à la matière organique (Pichot, 1978 a et b; Sedogo, 1981; Pieri, 1989; Hien, 1990; Hien et al. 1991).

Une autre étude qui date de 1980 et qui portent sur les effets comparatifs de l'enfouissement au labour de différents substrats organiques (tableau 4) permet de dire que ces substrats organiques agissent diversement en fonction de leur nature. Mais dans l'ensemble la tendance est l'augmentation du pourcentage du carbone de la fraction fine par rapport au carbone total du sol lorsqu'il n'y a pas d'apport concomittant d'engrais azotés.

Les résultats exploités ici concernent uniquement l'état de la matière organique dans le profil (0-60 cm) pour l'ensemble des traitements. L'état de la matière organique est comparé non seulement à celui du sol lors de la mise en place de l'essai en 1980 mais aussi à celui sous jachère naturelle.

Les analyses faites lors de la mise en place de l'essai (Sedogo, 1981) donnaient des teneurs moyennes en carbone de 0,47% sur les 20 premiers centimètres. En comparant ces teneurs avec celles des sols en 1988, on observe une différenciation entre les traitements due aux fumures.

Tableau 4: Effets des apports de substrats organiques avec ou sans un apport d'urée sur le profil organique et azoté du après 8 ans de culture.

		C. Total %		N. Total p.mille	
		Sans N	Avec N	Sans N	Avec N
Jachère	0-10 cm	0,42	-	0,34	-
	10-20 cm	0,32	-	0,29	-
	20-40 cm	0,30	-	0,29	-
	40-60 cm	0,24	-	0,29	-
Sol sans apport	0-10 cm	0,39	0,35	0,24	0,24
	10-20 cm	0,39	0,36	0,26	0,25
	20-40 cm	0,35	0,34	0,27	0,27
	40-60 cm	0,27	0,27	0,27	0,27
Pailles enfouies	0-10 cm	0,46	0,48	0,30	0,31
	10-20 cm	0,39	0,47	0,30	0,29
	20-40 cm	0,33	0,35	0,29	0,28
	40-60 cm	0,26	0,28	0,27	0,28
Fumier enfoui	0-10 cm	0,44	0,42	0,30	0,33
	10-20 cm	0,43	0,45	0,30	0,35
	20-40 cm	0,35	0,36	0,29	0,29
	40-60 cm	0,27	0,24	0,27	0,27
Composts aérobies enfouis	0-10 cm	0,46	0,44	0,32	0,32
	10-20 cm	0,47	0,42	0,32	0,28
	20-40 cm	0,34	0,31	0,28	0,28
	40-60 cm	0,26	0,27	0,27	0,27
Composts anaérobies enfouis	0-10 cm	0,51	0,46	0,35	0,33
	10-20 cm	0,48	0,56	0,32	0,32
	20-40 cm	0,37	0,30	0,31	0,31
	40-60 cm	0,25	0,26	0,28	0,28

Source : Sedogo et al. 1989

Le fractionnement de la matière organique des sols soumis à ces apports montre que la fraction fine semble varier très peu. En effet, en absence d'engrais azotés, elle est stable au niveau du sol et des composts anaérobies ; elle augmente de 31%. avec la paille, 10%. avec le fumier et 1,3%. avec les composts aérobies. L'effet des fumures azotées se traduit par une diminution de la matière organique contenue dans cette fraction, sauf pour le fumier où il y a une augmentation de 6%. La diminution est de l'ordre de 9%., 1,6%., 7,4%. et 2,7%. respectivement pour le sol sans apport organique, les pailles, les composts aérobies et les composts anaérobies. Comme dans le cas précédent on peut aussi constater que la mise en culture entraîne une augmentation du carbone de la fraction fine, donc une diminution de celui de la fraction grossière. Ceci est accentué avec les engrais azotés.

.Quand on apporte les engrais, l'augmentation baisse et dans certains cas est inférieur à celui du sol sous jachère.

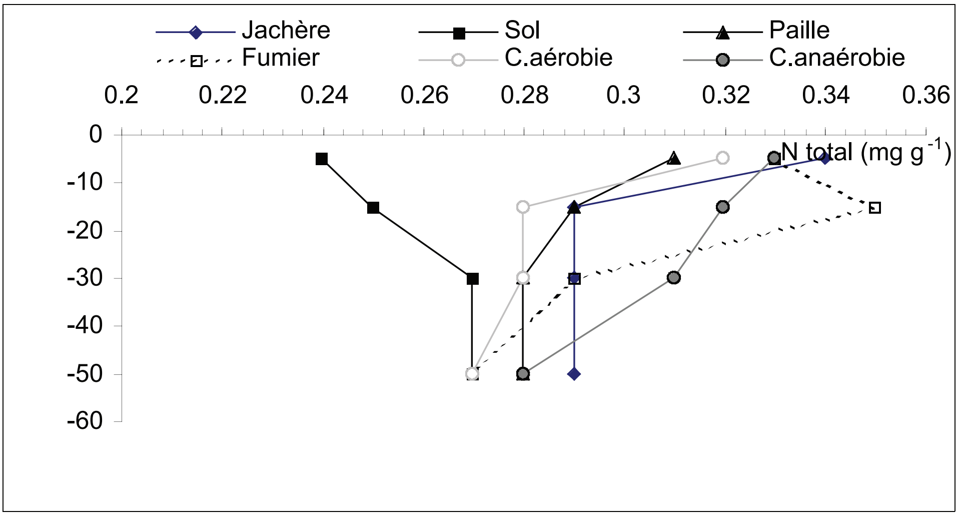

Figure 1 : Effets des apports de substrats organiques sur le profil azoté du sol (1971 à 1982)

Effets sur le carbone total du sol (tableau 3)

Ainsi, en absence de fumure azotée, il y a une baisse globale du stock organique du sol de 17%., ce qui fait une perte moyenne annuelle de l'ordre de 2%. Elle est de 2,1%. (0,25%./an) avec les apports annuels de 10t de pailles et 7,8%. (0,70%./an) avec le fumier. Le bilan semble équilibré avec le compost aérobie et, positif avec les composts anaérobies avec une augmentation globale de 8,5%. (environ 1%./an).

En présence d'engrais azoté, la baisse est plus accusée avec le témoin sans restitution organique avec une moyenne de 2,8%. par an. A l'exception des pailles, on enregistre une tendance à la baisse avec les autres substrats. Les apports annuels de 10t de pailles donnent un bilan équilibré.

Effets sur l'azote total du sol

En absence d'azote apporté (figure 1), la baisse de l'azote du sol est plus importante que celle du carbone (27,3%. soit en moyenne 3% par an) pour le témoin sans apport organique. Tous les substrats organiques entraînent une augmentation de l'azote du sol. Mais cette augmentation concerne seulement les 40 premiers centimètres.

En présence d'engrais azotés on constate la même baisse en absence de toute restitution. Les effets des substrats sont accrus sauf pour la paille. L'augmentation de l'azote total du sol concerne encore les 40 premiers centimètres. Par rapport à la jachère, on observe les mêmes tendances que pour le carbone du sol.

Ainsi donc avec les apports annuels de 10 t de substrats organiques sans engrais azotés, 54 à 62% environ de la matière organique du sol se retrouve dans la fraction grossière après 10 ans de culture continue. Avec les engrais azotés ces pourcentages sont respectivement de 61, 63, 64 pour les pailles, le fumier et les deux composts. En absence de tout apport organique après 10 ans de culture sans engrais azotés, on retrouve 58% de la matière organique dans la fraction grossière. Avec les fumures azotées, on retrouve 56%

Les caractéristiques des sols sous culture montrent que l'enfouissement des pailles permet d'augmenter le taux de matière organique du sol. Cette augmentation est accrue en présence d'engrais azotés pour ce qui concerne le stock d'azote organique. Ces résultats confirment ceux obtenus au Sénégal sur ces problèmes par Ganry et al. (1978 et 1979), Feller et al. (1979, 1981a et b), Cisse (1985) et au Burkina par Sedogo (1983) et Hien (1990).

Conclusion

En conclusion, il ressort de ces différentes études que les jachères jadis bien pratiqué en Afrique tropicale peuvent être effectivement une bonne pratique pour une gestion durable des terres. Le seul problème reste la pression foncière des populations qui ne permet plus d'avoir les jachères de longue durée.

Ces études ont également montré que la mise en culture de ces jachères s'accompagnait toujours par une baisse plus ou moins rapide des teneurs en matière organique et en azote indicateurs principaux du niveau de productivité des terres agricoles. La différenciation entre les pratiques de fertilisation montre l'importance des apports fréquents de matière organique dans ces systèmes. En effet ces apports permettent d'augmenter la matière organique du sol.

La fumure organo-minérale semble assurer une certaine stabilité du taux de carbone à court terme (apports annuels). Après cette période les teneurs semblent varier d'une année à l'autre en fonction des apports avec cependant une tendance à la baisse. Pour augmenter les taux de matière organique du sol il faudrait de fortes doses de fumure organique (de l'ordre de 40 tonnes ha^{-1} an^{-1})

Les caractéristiques des sols sous culture montrent que l'enfouissement des pailles permet d'augmenter le taux de matière organique du sol. Cette augmentation est accrue en présence d'engrais azotés pour ce qui concerne le stock d'azote organique.

L'ensemble des résultats ici présentés sur le carbone et l'azote du sol confirment la tendance à la dégradation de ces sols après leur mise en culture. En absence de toute restitution, les teneurs en matière organique baissent de l'ordre de 2 % par an en moyenne. Les restitutions n'empêchent pas entièrement ce processus, surtout avec les pailles et fumier sans engrais azoté. L'em≠ploi d'engrais azoté augmente la baisse du taux de matière organique par une augmentation de la minéralisation. Les pertes en matière organique dans ces conditions passent de 2 à 2,8 %. par an. Dans certaines conditions les apports organiques donnent des bilans positifs. Au niveau de l'azote organique les pertes sont plus importantes que celles du carbone. On constate cependant que l'emploi combiné des pailles et de l'azote permettait d'augmenter le stock d'azote organique du sol. Les variations des stocks organiques concernent surtout les 40 premiers cm du sol sous culture. Après la mise en culture, l'horizon 0-10 est celui qui est le plus affecté par les différents processus.

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Chapter 6

Role of legumes in soil fertility maintenance in Ghana

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Abstract

Soil nutrient reserves are being depleted because of continued nutrient mining without adequate replenishment resulting in declining soil fertility in Ghana. This has led to reduction in crop yields and soil degradation. The issue for improving agricultural productivity in Ghana is how to improve and maintain soil fertility despite the low incomes of smallholder farmers. Legumes play a central role in maintaining soil productivity in smallholder agriculture in Ghana. In this review, the option of using grain legumes for soil fertility maintenance in Ghana is presented. The data revealed that planted cover crop based fallows significantly increased crop yields, but this requires P and K fertilizer application to support better cover crop growth and biological nitrogen fixation (BNF). Generally, crops showed yield increases when rotated or intercropped with cover crops. The planting of leguminous crops generally led to positive changes in soil properties in most of the cases. Leguminous crops contribute to improve crop production and soil fertility through the release of N and other plant nutrients such as P and K through recycling. Most studies with cover crops showed that the quantity of biomass produced by a cover crop is not necessarily indicative of its effectiveness. The quality of the material produced should be considered as well. Large amounts of cover crop residues need to be applied for a good crop response since apparent N recovery is much lower for organic residues than with mineral fertilizer. Positive features of some cover crops such as easy establishment and weed suppression make the technology more likely to be accepted and adopted by farmers. To be sustainable, any alternative measures of improving soil fertility must be considered as complements rather than as substitute for inorganic fertilizers.

Keywords: *Alley cropping, Cover crops, Green manure, Guinea savanna, Soil fertility, Ghana.*

Résumé

Les réserves nutrientes des sols sont entre d'être considérablement réduites à cause de l'exploitation d'aliment sans le réapprovisionnnement adéquat à la suite de la baisse de la fertilité du sol au Ghana.. Celle-ci a amené à la réduction, dans la production de culture et de la dégradation du sol. La question pour améliorer la productivité agricole au Ghana est, comment améliorer et soutenir la fertilité du sol magré le revenu bas des petits cultivateurs. Les legumineuses jouent un rôle important dans le soutenement de la productivité du petit cultivateur au Ghana. Dans cette revue, l'option d'utiliser les grains legumineux pour soutenir la fertilité du sol au Ghana est présenté. Les données ont révélé que les couvertures de cultures bassés en jachére augmentent significanvirement la production de la culture, mais il fallait l'application d'engrais P et K pour soutenir un meilleur croissance de la culture et la fixation biologique azote (FBA). Généralement, les cultures ont montré une augmentation de la production quand elles étaient fait tourner ou quand elles sont plantées parmi des couvertures de cultures. La cultivation des cultures legumineuses généralement a amené un changement positif aux propriétés du sol dans plupart des cases. Les cultures legumineusses contribuent à l'amélioration de la production de culture et la fertilité en émissant la N et d'autres nutrientes de plantes telle que P et K par recyclage. Plupart d'études avec les couvertures de cultures ont montré que la quantité de biomasse produit par une couverture de cultures n'est pas nécessairement indicative de sa efficacité. La qualité de la materielle produite doit être considerée aussi. Une grande quantité de résidus de la couverture de culture doivent être appliques pour une bonne réponse de la culture car la récuppération N apparente est plus basse pour les résidus biologiques, que avec l'engrais minérale. Les caractérisques positives de la couverture des cultures tel que l'établissement facile et la suppression de la mauvaise herbe font la technologie plus plausible d'être agreée et adoptée par les cultivateurs. D'être durable, n'importe quelle mesure pour améliorer la fertilité du sol doit être considerée comme, des, complements plutôt qué une succédané pour les engrais artificieles.

Mots clés: *Cultures en couloir, savanna guinéenne, fertilité du sol, Ghana*

Introduction

Crop production in Ghana is limited by low and declining soil fertility, especially available nitrogen (N) and phosphorus (P). Increasing pressure on land due to increasing population and competing uses of land have shortened fallow periods leading to continuous cropping and consequently undesirable effects on soil structure and mineral status. The declining soil fertility problem is also aggravated by indiscriminate bush burning, continuous cropping and low nutrient application rates, over grazing among others. During the 1980s through the mid-1990s, the use of mineral fertilizer was regarded as a key option to cope with the problem of soil fertility in Ghana (Hailu, 1990). Applying these fertilizers soon became the preferred method for supplying crop nutrients. These fertilizers were relatively inexpensive because they were heavily subsidized by the government. Also they were easy to use and therefore eliminated the time and labour needed to grow green manure. Nevertheless, the massive devaluation of the Ghanaian currency and the withdrawal of subsidies for agricultural inputs resulted in increased cost of the fertilizers, making them prohibitively expensive for the average farm family with low income. It was therefore not surprising that by 1993, 90% of all the fields in northern Ghana did not receive any mineral fertilizers (Albert, 1994). In general, fertilizer application rate in sub-Saharan Africa is only 9 kg ha^{-1} compared with a global mean of 101 kg ha^{-1} (Camara and Heinemann, 2006). Also consumption of fertilizer N, P and K was 27% of the quantity of nutrients removed by the grain/tuber of food crops grown in Ghana from 1979 to 1988 (FAO, 1990). Despite the benefits of mineral fertilizers, after several years of widespread use, some problems may become apparent. Because these fertilizers are not from organic sources, they fail to replenish the soil organic matter. Nonetheless, fertilizer N can increase crop residue production and when this crop residue is returned to the soil, soil organic matter content could be increased. On the contrary, continuous use of N fertilizers, especially ammonium sulphate, induces soil acidity, which then requires liming when organic inputs are limiting (Djokoto and Stephens, 1961). One way of minimizing soil acidity from fertilizer N is by supplying N through biological N_2 fixation.

The critical issue for improving agricultural productivity in Ghana is how to build up and maintain soil fertility despite low incomes levels of smallholder farmers. Some scientists and policy makers maintain that organic fertilizers, such as farmyard manure and crop residues, are the key to improving soil fertility. The beneficial effects of manure on soil fertility are well documented and crop responses to manure application are often due more to the contribution of P and cations such as calcium (Ca) and Magnesium (Mg) other than the addition of N or due to physical effects of soil organic matter addition on water infiltration and retention. Nonetheless very little manure is available as livestock is often kept on free range. In some areas sufficient manure is available only for small areas surrounding family compounds (Runge-Metzger and Diehl, 1993; Albert, 1994). About two-thirds of the N applied to cereals is accumulated in the grain and will be exported during harvest. Much of the remaining N and a greater proportion of K are located in the stover and will not necessarily be cycled back to the soil because farmers presently remove almost the entire crop residues for uses with higher economic value, such as animal feed, fuel for cooking, building materials or raw material for handicrafts and often burn what is left. Baanante et al. (1992) in a farm survey in the forest zone of Ghana reported that 70% of crop residues served no useful agricultural purpose. Soil characteristics differ in the forest and savanna agroclimatic zones in Ghana, thus specific interventions may be required to overcome the soil fertility constraints. About 80% of the total area of Ghana is covered by savanna vegetation and the savanna regions constitute the most extensive potential land area for rapid agricultural development. Rhodes (1995) reported that uptake of N was generally least in the largely urban coastal savanna and greatest in the northern savanna, where relatively about 15 times more land was cropped. Thus targeting of N fertilizers to the savanna should be considered a priority. This is emphasized by the fact that the organic matter content of the savanna soils is much lower than the level present in forest soils (Acquaye, 1986).

In order to obtain appreciable yield under continuous cropping and the characteristics of low plant available soil N and P, external nutrient additions in the form of fertilizers have become inevitable. Incorporating N_2-fixing legumes into the cropping system enhances nutrient cycling and also provides the organic C and N necessary for maintaining soil organic N fractions. In general, soil fertility can be maintained or increased using an integrated approach such as the use of fallows, biological nitrogen (N_2) fixation (BNF) by legumes, the use of crop residues, the application of mineral fertilizers and the use of household wastes and manure (Albert, 1994). Increased use of organic and inorganic fertilizers can create a win-win situation, by promoting more efficient crop production and reducing soil degradation. This review is an attempt to summarize primarily results of on-station and on-farm experiments involving the use of leguminous crops for soil fertility replenishment in Ghana. Although a fair amount of information was gathered, I cannot claim to have accessed and analyzed the complete set for Ghana.

Soil fertility in Ghana

The interior savanna agro-ecology, found in the northern part of Ghana, occupies nearly two-thirds of the country's total land area. The zone consists of the Guinea and Sudan savanna and often experience hot, distinct dry and wet conditions. The characteristic unimodal rainfall regime starts from April and ends in October and ranges from 900 – 1200 mm. The Sudan savanna savanna has similar conditions but rainfall amounts are lower (900 – 1000 mm) and the dry period is also longer. The rainfall in the forest zone is characteristically bimodal and ranges from 1200-1400 mm. The major season starts from April to about mid-July, with the minor season occurring in September and October. The minor season is followed by a long dry season from November to end of March or early April. The Coastal savanna also experiences a bimodal rainfall regime but annual rainfall amounts are very variable from 750 – 1000 mm.

Soils in Ghana generally are moderate to low in nutrient status (Table 1). They have low organic C and total N contents because of low biomass production and a high rate of decomposition. Nitrogen and P are limiting nutrients. Soil P stocks are low, but the low activity clay (kaolinite is the predominant clay mineral present) of these soils has a relatively low capacity to fix added P. Therefore the P requirement for maximum yield is often low. The sandy-textured surface horizons especially in the savanna and to a less extent in the forest-savanna transition zone have low organic matter content which limits their moisture-holding capacity and potential for growing annual crops. The savanna soils are less leached and less acidic but mainly of low fertility status. Organic matter content and cation exchange capacities of soils in the interior savanna are very low, mainly as a result of the predominantly grass vegetation and the almost complete removal of bases leaving only sesquioxides minerals of aluminium, iron and manganese. Less organic matter in the savanna zone reflects the high frequency of cropping coupled with bush burning, ploughing (instead of slash and burn land preparation prevalent in the forest areas) and the consequent high soil temperatures on unshaded soils. The coastal savanna soils are heavy clay-textured and cultivation could be difficult. In the forest zone, the soils are leached, acidic, deeply weathered and easily eroded. Additionally, they have higher levels of organic matter and are less compacted compared with soils in the savanna zone. Length of fallow is often greatest in the forest and transition zones and least for savanna zone.

Table 1: Selected chemical properties of soils in various ecological Zones of Ghana, 1983

Zone	No.of sites	Bulk density (g cm^{-3})	pH	CEC (me/ 100g)	Organic matter (%)	P retention (%)	Length of fallow (yr)	No.of years since fallow
Coastal savanna	14	1.27	6.6	7.3	1.86	5.6	1.8	5.6
Forest	34	1.16	6.5	8.5	2.81	10.8	3.2	3.0
Transition	36	1.25	6.4	7.5	1.96	7.6	2.9	5.3
Guinea savanna	51	1.31	6.4	3.9	1.24	4.4	2.0	6.4
All sites	135	1.26	6.4	6.4	1.88	7.0	2.5	5.1

Source: Analysis of soil collected from representative sites throughout Ghana for Ghana Grains Development Project (GGDP) by Dr. Edmeades (unpublished data)

Crop rotation effect on crop yields

An alternation of crops with diverging ecological requirements in a rotation is very beneficial for the maintenance of high soil productivity under permanent cultivation. Tropical grain legumes can fix substantial amounts of N under favorable conditions, but a greater proportion of this N is often harvested in the grain. Apart from direct benefit from biological N_2 fixation to maintain the legume grain yield, the subsequent crop in rotation can use any N left in the soil. Thus the introduction of N_2 fixing legumes into continuous cropping systems can therefore serve as cheap, clean and renewable source of N for the non-legumes involved in such systems. Through N_2 fixation, the legumes are able to contribute N to the soil through the mineralization of their residues left in the field thereby building up the N status of the soil. Biological N_2 fixation from legumes can sustain tropical agriculture at moderate levels of output. At high crop yield levels, however, organic N inputs are likely to be insufficient and therefore must be supplemented with inorganic fertilizers. Thus organic sources of nutrients should be complementary to the use of mineral fertilizers. Grain legumes have long been recognized as an important component of crop rotation systems in the tropics and substantial increases in grain production can be expected when cereals follow leguminous crops in the savanna zone of Ghana (Härdter, 1989; Kaleem, 1989; Schmidt and Frey, 1992; Horst and Härdter, 1994; Buah, 2004; Fosu et al., 2004). Various field experiments have showed that crop rotation of maize with various legumes was beneficial for maize production and that maize following groundnut [*Arachis hypogaea* (L.)] often had the greatest yields when compared with maize following other legumes (Härdter, 1989; Horst and Härdter, 1994; Schmidt and Frey, 1992).

Maize grain yields after various legumes were increased by 89-95% compared to maize grown in monoculture (Kaleem 1989). In 1992, Härdter and Frey reported that maize yield increases of more than 600 kg ha^{-1} compared to other cropping systems were realized when maize was planted after cowpea (*Vigna unguiculata* (L.) Walp. sp. *Unguiculata*). Additionally, the same authors observed that higher amounts of organic N were mineralized from cowpea residues incorporated into the soil at harvest during the previous year. Further, grain yields of unfertilized pearl millet were significantly increased by 12.1, 22.6 and 24.2%, when grown after pigeon pea [*Cajanus cajan* (L.) Millsp.], groundnut and cowpea, respectively, on a savanna alfisol (Kaleem, 1989).

In another study that examined the benefit of annual legumes in rotation with sorghum, a 30 to 48% yield increase was observed for sorghum following groundnut when compared to continuous cultivation of sorghum in the Guinea savanna of Ghana (Schmidt and Frey, 1992; Buah, 2004). The result for groundnuts is supported by evidence from previous work on maize (Härdter, 1989; Kaleem, 1990; Schmidt and Frey, 1988; Horst and Härdter, 1994) and a conclusion appears to be justified that in northern Ghana a good crop of groundnut is likely to benefit the N nutrition of a subsequent cereal crop (Table 2). In addition, the results obtained by Buah (2004) indicate that 40 kg fertilizer N ha^{-1} applied to sorghum on former groundnut plots was just as effective as 80 kg N ha^{-1} applied to former sorghum plots and at all levels of N application, the yield of sorghum after either groundnut, cowpea or soybean [*Glycine max* (L.) Merr.] was greater than the yield of sorghum in the continuous sorghum cultivation. The studies further revealed that because of greater N contribution, groundnut is a better preceding crop for sorghum production than cowpea, soybean and sorghum in that order. Koli (1973) observed that although fertilizer requirements of yam are low, when grown after cereals, yam would need up to 60 kg N ha^{-1}, but after groundnut, little or no N should be added. It has therefore been recommended that if returned to the soil, groundnut residues can boost cereal yields.

Tabel 2: Influence of preceding crops and nitrogen fertilizer on grain yield of maize crop sequence trial in 1981-1986 at Nyankpala, Guinea savanna zone of Ghana.

Preceding crop	kg N ha^{-1} applied to maize	Maize grain yield t ha^{-1}				
		1982	1983	1984	1985	1986
Maize	0	1.04	0.38	1.19	1.72	2.35
	60	2.80	1.58	4.72	4.47	3.74
	Mean	1.92	0.98	2.96	3.10	3.04
Groundnut	0	2.83	1.66	3.02	3.62	3.35
	60	4.12	3.20	6.36	5.55	4.06
	Mean	3.48	2.43	4.69	4.58	3.70
Sorghum	0	0.75	0.26	0.58	1.40	2.07
	60	2.03	1.21	3.45	3.80	3.12
	Mean	1.39	0.74	2.01	2.60	2.59
LSD (0.05) preceding crop		0.64	0.45	0.72	0.45	0.27
LSD (0.05) N level		0.24	0.16	0.34	0.16	0.23

Source: (Schmidt and Frey, 1988)

Changes in soil chemical and physical properties under crop rotation

Cereal and legume rotation effects on soil improvement have been reported by several scientists in Ghana (Härdter, 1989; Kaleem, 1989; Schmidt and Frey, 1992; Horst and Härdter, 1994; Fosu et al., 2004). The results that groundnut is a better preceding crop than soybean for cereal production may not be surprising because soybean residues are lignified (~10% lignin) at harvest with C/N ratio around 45:1 causing N immobilization when they are added to the soil (Toomsan et al., 1995). Groundnut residues on the other hand, can contain >160 kg N ha^{-1}, are less lignified (~5% lignin) and are rich in N, as the crop is harvested while green. With most legumes, there is a net contribution from N_2 fixation only if the legume residue is returned to the soil or if substantial amount of the leaves fall before harvest. The most beneficial effect of legumes is evident where the residues are incorporated into the soil. This could be attributed to faster release of N from legume residues because of direct contact with the soil as compared to surface application which results in slower decomposition and N release because of less contact with soil enzymes (Costa et al., 1989). In estimating the N contribution as nitrogen fertilizer replacement value (NFRV) which is the amount of fertilizer N required to achieve the same yield in continuous non-legume as was attained by the non-fertilized non-legume that followed a legume, Kaleem (1992) reported NFRV value of 43-52 kg N ha^{-1} while working on cowpea. This figure was much greater than the 20 kg N ha^{-1} obtained by Carsky et al., 1997 with soybean residues in the Guinea savanna of Nigeria, possibly because of poor quality of soybean residues (N<1.5% or C:N>25) compared to cowpea residues. There is also evidence that because of the ability to fix atmospheric N_2, legumes remove less inorganic N from the soil compared to cereals thereby leaving more N for the subsequent cereal in rotation (Kaleem 1989). This phenomenon has been termed the "N sparing effect" (Peoples et al., 1995). In spite of high amounts of N translocated to soybean grain, it is expected that increased N_2 fixation should result in more N contribution through soybean residues. Some promiscuous soybean varieties have a greater potential to add N to the soil and should be recommended to smallholder farmers. Long duration grain legumes such as pigeon pea and some varieties of cowpea input N through a substantial amount of biomass in the form of roots and leaves that fall before harvest. This means that a relatively large proportion of the fixed N remains in the field potentially benefiting subsequent crops.

Results reported by Horst and Härdter (1994) indicated that improvement of the nutrient status of crops succeeding legumes was only one aspect of the positive rotation effect and that the improvement of soil physical properties was another important factor. In general, legume-induced increases in cereal yields are due to greater early season N availability, enhanced infection of cereal roots with arbuscular mycorrhiza, decreased nematode infestation, increased pH, improved P availability through changes in soil chemistry and enhanced phosphatase release (Resck et al., 1982; Wade and Sanchez, 1983; Reddy et al., 1986; Becker et al., 1998; Bagayoko et al. 2000; Alvey et al. 2001; Fosu, et al., 2004; Marschner et al. 2004). Other effects of legumes that contribute to yields beyond the simple N effects include improved soil aggregate stability (Burns and Davies, 1986) and amelioration of compacted soils (Jordan et al., 1956; Hulugalle et al., 1986). In spite of these other effects, the N supplied by a legume is usually taken as the basis for determining its worth to an agricultural system.

Uptake of N by succeeding maize in rotation is always higher than uptake in maize monocropping. For example, in the Guinea savanna zone of Ghana, N uptake by maize grown in rotation with cowpea in 1985 was 58 kg ha^{-1} whereas uptake by monocropped maize was 36 kg ha^{-1} without N fertilizer applications (Horst and Härdter, 1994). This was most certainly because all cowpea residues were maintained in the plots while the entire aboveground biomass of maize was removed after maize cropping. Thus a considerable amount of N was returned to the soil by the cowpea crop residues and this explains the higher potential net N mineralization and the higher nitrate content of the topsoil at the beginning of the cropping periods under maize after cowpea on the unfertilized plots. With N application, however, there were no differences in net N mineralization. Moreover, higher nitrate contents in the subsoil under continuous cropping of maize over most of the cropping period even without N application indicate that the use of nitrate rather than its supply was the more limiting factor for monocropped maize.

Root-length densities of maize determined at 34 days (8 leaf stage) and 49 days (beginning tasseling) after planting were significantly lower in monocropped maize than in maize grown in rotation with cowpea. Limited utilization of soil nitrate from the subsoil by maize in monoculture could be due to restricted root growth. Inhibited root growth especially in maize monocropping could be due to deterioration of soil physical properties which may be characterized by infiltration rate, bulk density, aggregate stability and water holding capacity (Horst and Härdter, 1994). Such soil physical properties appeared to be better under maize-cowpea rotation compared to continuous cultivation of maize (Table 3). In contrast, other reports indicate that yield decline in maize monocropping might be due to allelopathic effects of maize.

Table 3: Soil physical properties as influenced by cropping systems after three years of continuous cropping in the savanna zone of Ghana.

Cropping system	Infiltration mm/min	Bulk density g cm^{-3}	Aggregate stability (Relative)[a]
Maize-cowpea rotation	2.56	1.48	1.00
Cowpea-maize rotation	2.57	1.46	1.37
Maize-cowpea relay intercropping	2.37	1.52	0.63
Maize-cowpea mixed cropping	2.15	1.52	0.83
Maize monocropping	2.34	1.49	0.59
Fallow	8.00	1.42	2.70

Source: Härdter, 1988.

[a]*Maize-cowpea rotation = 1.00*

Cultural practices such as crop rotation involving grain legumes are said to support good crop growth and consequently contribute to reducing soil erosion. These cropping systems offer better and continuous vegetative cover which protects the soil against direct raindrop impact. Soil erosion studies at Manga near Bawku in the Sudan savanna zone with average rainfall of about 950 mm a^{-1} indicate that regardless of the tillage system, early millet or sorghum rotated with groundnut reduced soil loss when compared with bare plots (Halm and Asiamah 1992). Soil lost from rotated plots ranged from 0.69 to 1.44 t ha^{-1} when compared with a value of 2.24 t ha^{-1} for bare plots. Legumes may differ considerably in soil N uptake. Thus observations of low soil-N uptake by some legumes cannot be generalized. In assessing N fixation of various leguminous crops on an Alfisol in the Guinea and Sudan savanna of Ghana, Kaleem (1992) reported that the N content and N_2 fixing capacities of various legumes varied considerably not only among different species but also among cultivars of the same species (Table 4).

Table 4: Estimates of nitrogen fixed on smallholder farms in the Savanna zone of by various legumes

Legume	N_2 fixed kg ha^{-1}
Cowpea (cv. Vita 7)	51[a] (23)[b]
Cowpea (cv. Sawla local)	54
Cowpea (cv. KN-1)	43
Groundnut (cv. India)	7 (33)
Groundnut (cv. Manipintar)	28 (32)
Bambara groundnut	40 (37)
Stylo (cv Cook)	16 (14)
Stylo (cv Verano)	37 (1)
Centrosema	9 (1)
Chick pea	3
Lablab	37 (51)
Crotalaria juncea	88

Source: Kaleem, 1992.

[a]N fixed by the legume in the Guinea savanna zone

[b]N fixed by the legume in the Sudan savanna zone

Härdter (1988) estimated the contribution of mineralization of cowpea residues incorporated into the soil at the end of the cropping season to the N supply to the plants by soil incubation under laboratory conditions. The author reported that about 50 kg N ha^{-1} were mineralized during the 6 weeks of incubation. The N-liberation from cowpea residues was not more than 20 kg N ha^{-1} higher compared with the treatment without residues confirming that only a minor part of the cowpea residues of the previous year contributed to the N nutrition of maize in the following year.

As biomass and grain yields of sole-cropped grain legumes under small holder conditions in Ghana are often small (500 kg ha^{-1} of grain), the amounts of N_2 fixed are barely significant. For example, in the savanna zone with 950-1000 mm a^{-1} of rainfall where cowpea is a staple grain legume, the amount of N_2 fixed was estimated to be 53 kg ha^{-1} (Härdter and Host, 1991). This was relatively low compared with reported values for the same cowpea of up to 354 kg ha^{-1} (Agboola and Fayemi, 1972) and other grain legumes in Nigeria. They explained that the lower N_2 fixation value was probably due to high nitrate-N contents in the soil at the beginning of the cropping season and a high sensitivity of the legume/rhizobium symbiosis to nitrate. This they said was indicated by the poor nodulation when N fertilizer was applied. Some pest problems associated with low soil fertility are decreased when fertility is improved. For example, besides improving soil fertility, soybean grown in rotation with maize, sorghum or pearl millet in soils infested with the parasitic weed striga

(Striga hermonthica), a major cereal pest in the Guinea savanna zone, has been found to encourage suicidal germination of the parasitic weed, thereby reducing its seed pool (Kombiok, 1996).

Effect of planted fallow on crops

Crop yield response to herbaceous fallow

Leguminous cover crop systems apparently were more extensively tested than tree fallow systems in Ghana. In Table 5, maize grain yields obtained from Crotalaria spp green manures plus fertilizer were significantly greater than those obtained from plots that were planted to green manures only or the recommended rate of fertilizer for maize (90-38-38 kg ha^{-1} as N, P_2O_5 and K_2O) only (Quainoo, 2001). Though combined use of Crotalaria fallow and inorganic fertilizer resulted in the greatest maize yields when compared with either Crotalaria or inorganic fertilizer effects alone, it resulted in lower marginal rates of return due to the high cost of inorganic fertilizer in Ghana. High seed rate of may be recommended for fallow species in the Guinea savanna zone of Ghana to delay development of weeds. A synthesis of results of trials of a Mucuna fallow system by Carsky et at. (2001) suggested that in simultaneous intercropping systems, the yield of maize associated with Mucuna is decreased dramatically as the Mucuna smothers the maize. However, maize yield reduction from relay intercropping of Mucuna at 40 to 50 days after maize planting is only about 5%. Additionally, Osei-Bonsu et al. (1995) reported that at all 3 locations in the forest zone of Ghana, yield of maize following sole Mucuna was consistently higher than those obtained from monocropped maize; simultaneous intercropping of maize and Mucuna or relay intercropping of Mucuna at 45 days after maize planting (Table 6).

Table 5: Maize grain yield under a fallow of Crotalaria species in the Sudan savanna zone of Ghana

Treatment	Grain yield t ha^{-1}	
	Fallow of 50 kg ha^{-1} of Crotalaria seed	Fallow of 100 kg ha^{-1} of Crotalaria seed
C. ochroleuca	0.9	1.3
C. retusa	0.8	1.1
C. ochroleuca + fertilizer	2.9	3.4
C. retusa + fertilizer	2.8	3.3
Fertilizer only	1.7	1.7

Source; Quainoo, (2001).

Table 6: Maize grain yield as affected by preceding crop in the major season of the forest zone of Ghana, 1983

Preceding crop	Grain yield t ha^{-1}			
	Hiawo	Ejura	Seko	Mean
Maize + N	3.7	4.0	2.7	3.4
Maize (No N)	1.0	1.3	1.1	1.2
Cowpea	1.6	2.1	2.0	1.9
Maize + cowpea	1.8	2.4	1.7	1.9
Sole Mucuna	4.9	3.9	3.6	4.2
Maize/Mucuna interplanted simultaneously	3.4	3.3	2.3	3.0
Mucuna intercropped at 45 days into maize	2.2	4.2	2.5	3.0
LSD (0.05%)	1.4	1.2	1.3	0.7
CV %	32.5	23.3	35.0	29.5

Source; Osei-Bonsu et. al. (1995)

In a study on a typic plinthic Planleustalf in the savanna zone of Ghana, Kombiok and Clottey (2003) reported that maize grain yields obtained after two years of interplanting with Mucuna was greatest under 6 *wk* after planting followed by 8 *wk* after planting and the least was obtained from 10 *wk* after planting (Table 7). They concluded that the greatest yields of maize from relay intercropping of Mucuna at 6 *wk* after maize planting was due to the beneficial effects of the decay of the greatest Mucuna biomass produced in that treatment in the previous years. It is clear that if Mucuna does not accumulate substantial biomass, then it will not accumulate sufficient N nor suppress weeds. The same authors observed that some management of Mucuna to ensure it does not smother the maize crop in association is necessary to reduce competition for light in favour of the maize crop. In general, a number of management factors influence the magnitude of yield benefit from Mucuna cultivation. The benefit of Mucuna fallow increases as the interlude between slashing and planting of the subsequent crop decreases. Additionally, incorporation of Mucuna residues has a much greater effect on subsequent maize yields than leaving them on the soil surface as mulch.

Table 7: Maize grain yield as affected by time of interplanting Mucuna in maize and after two years of continuous Mucuna in northern Ghana

Treatment[a]	Grain yield t ha^{-1}		
	1996	1997	1998
Maize without Mucuna	1.8	1.2	1.1
6 WAP	1.5	1.6	1.9
8 WAP	1.2	1.1	1.7
10 WAP	1.1	1.5	1.3

Source; Kombiok and Clottey, (2003).

[a] *WAP = Weeks after planting maize*

With Devil bean *(Crotalaria retusa)* fallow the addition of 20 kg P ha^{-1} as rock phosphate incorporated in the soil, produced the highest sorghum yield of 2.3 t ha^{-1} when compared with Calopogonium and Mucuna planted fallow plots. Calopogonium residue application resulted in sorghum grain yield of about 1.5 t ha^{-1} and that of Mucuna and weed fallow were similar and below 1.0 ha^{-1} (Fosu el at., 2003 unpublished). Dry matter yields of the weed fallow, Mucuna, Calopogonium and devil bean were 4.1, 5.0, 8.1 and 17 t ha^{-1}, respectively, and the N input ranged from 20 to 250 t ha^{-1}.

Fosu et al. (2004) reported that the dry matter yield of Mucuna, Calopogonium, sunn hemp (*Crotalaria juncea)* and devil bean *(Crotalaria retusa)* fertilized with 17 kg P ha^{-1} and 33 kg K ha^{-1} ranged from 5.0 to 14.0 t ha^{-1} across three locations in northern Ghana with a corresponding total N accumulation of 114 to 301 kg ha^{-1}. Further, the authors observed that when the cover crops residues were incorporated, succeeding maize grain yield increased 2 to 4-fold above the 1-yr weed fallow control. Calopogonium was the best cover crop in increasing maize grain yields. Greater maize grain yields under Calopogonium were due to higher Calopogonium residue quality. Though devil bean produced the greatest dry matter and accumulated the most N, it did not increase maize grain yield commensurate with its dry matter and N yields due to high N immobilization

Changes in soil chemical and physical properties under cover crops

Benefits from leguminous cover crops include improvement in soil water conditions as a result of decreased surface runoff, increased soil organic matter and improved soil structure, and decreased evaporation losses. Cover crops also offer soil erosion protection and utilize residual nitrates, thereby reducing potential for denitrification or leaching losses. They are able to conserve water and supply a substantial part of the N needed for optimum yields of non-leguminous crops. Several legume species are adaptable in such cropping strategies (Dogbe et al., 2000; Fosu et al., 2004). Additional benefits such as effective weed suppression or other uses may be necessary for farmers to adopt use of green manures. Increases in crop yields and soil improvement that have occurred in some studies make using leguminous cover crops a potentially important cropping strategy for controlling noxious weeds and restoring the crop productivity of degraded soils (Fosu et al., 2003; Fosu et al., 2004; Frey, 2001). Cover crops therefore hold the promise of restoring at least some of the soil productivity lost due to the exploitative soil management practices of the past.

Leguminous fallows have been used in northern Ghana to accumulate N from BNF, smother weeds, and improve soil physical properties. (Fosu et al., 2004; Frey, 2001). The use of cover crops in improved fallow technologies implies growing the cover crop at the expense of a food crop or cash crop. Even though green manures gave greater yields of subsequent crops than rotation with grain legumes such as cowpea, they are less attractive to the farmer as they occupy the land without a direct economic output. This may not be a viable option in areas of acute land shortage such as the densely populated areas of the Upper East region where farmers cannot afford to leave their land fallow. Improved fallows seem to be viable options in the interior savanna and the forest zones with relatively large farm size and widespread use of grass fallows.

The most popular cover crop species used in Ghana are of the genus Mucuna, Crotalaria Pueraria, Dolichos and Calopogonium (Fosu, 1999; Frey, 2001). Devil bean grows wild in northern Ghana under diverse soil conditions. The use of Mucuna in short-term fallows is expanding in Ghana (Osei-Bonsu and Buckles, 1993) because it has good biomass production in diverse environments, consistent positive impacts on main crop yield and effective weed suppression. Researchers and extension staff of the Ministry of Food and Agriculture (MOFA) are promoting the use of Mucuna as a cover crop in cereal production and to regenerate degraded soils. Empirical evidence show that Mucuna smothers imperata weed (Imperata cylindrical) and fixes N in many parts of West Africa including Ghana (Adu-Tutu et al., 1995; Chikoye and Elekeme, 2000).

In an experiment to compare three dates of interplanting Mucuna in maize at 6, 8 and 10 *wk* after planting maize and two cropping systems (bush fallow and control treatments of sole maize without Mucuna) in the savanna zone of Ghana, Kombiok and Clottey (2003) reported that Mucuna interplanted at 6 and 8 wk after planting maize increased soil N by 30% in each case and organic matter was also raised by 38, 39 and 48% for 6, 8, and 10 wks after planting maize, respectively (Table 8).

Table 8: Effect of time of interplanting Mucuna in maize on selected soil chemical properties after two years of Mucuna in Ghana

Treatment	Total N (%)	P (mg kg^{-1})	K (mg kg^{-1})	pH	Organic matter (%)
Control	0.024c	15.59a	49.90	4.18c	0.89d
6 WAP[2]	0.043a	11.96b	45.65	4.50b	1.33b
8 WAP	0.043a	11.86b	44.25	4.58a	1.34b
10 WAP	0.036b	11.28b	46.16	4.62a	1.32b
Bush fallow	0.050b	15.43a	48.20	4.32b	1.07c

Source: Kombiok and Clottey (2003)

[1] *For a factor, means followed by the same letter in a column are not significant at 5% level of significance*

[2] *WAP = Weeks after planting*

Cover crops should have the capability to grow rapidly and provide ground cover in order to protect the soil from erosion. In a study by Frey (2001), Mucuna was able to cover the ground earlier than Calopogonium. At one of the sites, percentage cover at 16 weeks after germination was 80 for Mucuna and 50 for Calopogonium, respectively. The land was tilled before planting of cover crops and this may have been the reason for faster and better ground cover at the Tumu site compared to the Langbensi site. Leaving Mucuna plants on the ground for more than 18 wk often result in the shedding of leaves especially during the dry season and the reduction of legume N contribution to the soil. Once established, certain legumes like Calopogonium and Mucuna are effective in self-reseeding systems. Thus their seeds are dispersed during the dry season before they are cut down and buried, and this in part, will sustain the regeneration of cover crops in the succeeding year. The major advantage of the practice is to avoid having to plant the legume cover crop each year, thus saving the cost of annual seeding.

Adequate soil fertility for sustained crop yields can be obtained with combined use of mineral fertilizers and organic materials. Nitrogen fixation has been reported to be affected by P availability especially in soils low in P (Fosu et al., 2004). Moreover the N release from the residues of leguminous crops is enhanced when small amounts of fertilizers are added. In savanna soils where the available P is low, the application of P fertilizer to leguminous crops, apart of enhancing N fixation should increase P status to levels sufficient for the subsequent crop (Fosu, 1999; Schmidt and Frey, 1992). It is obvious that the use of cover crops to supplement N fertilizer, conserve water and help control soil erosion is indisputably feasible from an agronomic viewpoint. However, Quainoo (2001) reported that it may not be economically feasibly because of several economic factors, including the cost of N fertilizer, the value of the harvested cover crop and the value of the additional crop yield. The value of cover crops as food or feed is not evident, and since they do not have other uses, there is no market for them.

Fosu (2003) reported that devil bean and *Mucuna pruriens* had high N concentration in addition to higher yields resulting in significantly higher total N accumulation than Sunnhemp and *Calopogonium mucunoides* in the savanna zone of Ghana (Table 9). The proportion of N derived from the atmosphere (%Ndfa) by Mucuna, devil bean, sunnhemp and calopogonium which have been fertilized with 17 kg P ha^{-1} and 33 kg K ha^{-1} ranged from 65 to 81% with Mucuna giving the highest %Ndfa and Calopogonium the least. The total N_2 fixed ranged from 59 to 110 kg ha^{-1} with devil bean giving the highest and the least from Calopogonium. However, the N release data of Fosu (2003) need to be interpreted with caution because not all N lost from the litterbags may be immediately available for plant use. The dry matter yield of the cover crops was positively correlated with the amount of N_2 fixed but not with the percent of N derived from the atmosphere. This indicates that the dry matter accumulation of N_2 fixing legume may be a good indicator of the amount of atmospheric nitrogen that can be fixed but the N_2 fixed as a fraction of N accumulated is not dependent on the dry matter yield.

Table 9: Total dry matter yield, N concentration , total N accumulation and total N_2 fixed by cover crops and reference plant at flowering in Ghana

Cover crop or reference crop	Dry matter (t ha^{-1})	N conc (%)	Total N (kg ha^{-1})	N_2-fixed (kg ha^{-1})
Devil bean	7.3	1.96	43.7	109.5
Mucuna	6.1	2.15	131.7	63.8
Calopogonium	5.3	1.74	91.8	106.2
Sunn hemp	5.0	1.79	89.0	59.4
Cassia	1.0	1.90	18.9	NA[1]
LSD (0.05)	1.6	0.23	32.4	22.5

Source; Fosu, (2003). [1]*NA = Not applicable*

Annual herbaceous leguminous cover crops have shorter duration and lower biomass accumulation and therefore provide lower N inputs than woody leguminous fallows. Sunn hemp residues are less lignified (~8% lignin) at harvest with C/N ratios around 18:1 so they tend to release N faster when they are added to the soil (Fosu, 2003). Devil bean, Mucuna and Calopogonium residues on the other hand, are more lignified (~10-14% lignin) and thus released their N at a slower rate. In northern Ghana, Kaleem (1992) reported that sunn hemp fixed 88.2 kg N ha^{-1} during the cropping season in the Guinea savanna and this was the highest N_2 fixation recorded among all the legumes tested. In contrast, Fosu (2003) recorded the highest N_2 fixation of almost 110 kg ha^{-1} for devil bean in laboratory studies but he added that the rate of release of N was faster for sunn hemp than for devil bean. Sunn hemp therefore appears to be a suitable post harvest green manure in lowland rice fields where soil moisture may be adequate to sustain viable legume/rhizobium association (Kaleem, 1992).

In another study, Fosu et al. (2004) reported that total N accumulation of Mucuna, Calopogonium, sunn hemp and devil bean fertilized with 17 kg P ha^{-1} and 33 kg K ha^{-1} ranged from 114 to 301 kg ha^{-1} (Table 10) across three locations in northern Ghana. Though devil bean produced the greatest dry matter and accumulated the most N, it did not increase maize grain yield commensurate with its dry matter and N yields due to high N immobilization. Low quality of devil bean residue in terms of high lignin/N ratio and higher cellulose content is responsible for the high N immobilization. Various studies have shown that the quantity of biomass produced by a cover crop is not necessarily indicative of its effectiveness (Fosu, 2003; Fosu et al., 2004). Consequently the selection of legumes for soil fertility improvement should not be based on the total dry matter production of the legume only but also on other parameters such as residue quality, decomposition and mineralization rate.

Table 10: Total N content, total N uptake, P uptake, apparent N recovery (ANR), aboveground dry matter (DM) yield and maize grain yields at three locations in northern Ghana.

Location	Treatment	Total N (kg ha^{-1})	N-upkate (kg ha^{-1})	P-upkate (kg ha^{-1})	ANR (%)	Dry matter (t ha^{-1})	Maize yield (t ha^{-1})
Cheshegu	Devil bean	301.0	59.1	20.2	13.6	14.0	2.4
	Calopogonium	181.0	76.3	23.5	31.7	8.5	3.2
	Mucuna	151.0	52.2	14.2	22.0	7.1	2.3
	Sunn hemp	122.0	47.0	14.5	23.0	5.0	2.1
	NPK fertilizer	60.0	64.2	15.8	75.4	NA	2.7
	Weed fallow	ND	19.0	6.8	NA	ND	0.9
	LSD (0.05)	38.7	7.1	2.4	6.2		0.4
Tingoli	Devil bean	277.0	64.0	14.8	16.2	14.0	2.9
	Calopogonium	152.0	67.6	15.6	31.9	8.4	3.1
	Mucuna	131.0	50.2	11.4	23.6	7.0	2.4
	Sunn hemp	114.0	48.5	10.9	25.8	5.0	2.3
	NPK fertilizer	60.0	50.7	10.1	52.5	NA	2.0
	Weed fallow	NA	15.8	2.8	NA	NA	0.7
	LSD (0.05)	14.0	9.7	2.5	10.0		0.3
Nyankpala	Devil bean	276.0	52.1	18.4	13.1	14.0	2.7
	Calopogonium	207.0	61.9	20.6	22.0	10.7	3.0
	Mucuna	173.0	56.1	15.1	21.2	8.6	2.5
	Sunn hemp	115.0	40.1	13.1	19.0	5.0	1.8
	NPK fertilizer	60.0	44.9	12.6	44.3	NA	1.9
	Weed fallow	ND	18.3	5.9	NA	ND	0.9
	LSD (0.05)	22.4	5.4	2.3	7.3		0.3

Source: Fosu, (2003).

= NA = not applicable;   = ND = not determined

Nutrient uptake and apparent N recovery

Palm (1995) reported that the recovery by the crop of N from the leaves of leguminous plants incorporated into the soil (10-30%) is generally lower than recovery from N fertilizers (20-50%). Much of the remaining 70 to 90% of the applied organic N not used by crops or leached is incorporated into labile pools of soil organic N and C. An apparent N recovery (ANR) by maize from cover crops estimated by the difference method was 22% compared with 57% for mineral fertilizer across several locations in northern Ghana (Fosu et al., 2003). Within the cover crops tested, the highest maize N uptake and ANR was realized from Calopogonium and the lowest from devil bean. The lower ANR obtained from organic sources compared with mineral fertilizer emphasizes the need to apply larger quantities of organic residues to match fertilizer response. Moreover, the lower N recoveries also emphasize the fact N supply from organic residues alone cannot be used to explain the increased cereal yields that is observed with the use of cover crops in crop production. The highest ANR was recorded on soils with less acid environment that is more favorable for N mineralization and assimilation.

Nodulation of cover crops

Dogbe et al., (2000) reported that poor nodulation and N_2 fixation of Mucuna and many legumes in Ghana may to a large extent be attributable to low rhizobial population in the soil. According to them, for effective nodulation, the number of rhizobia per gram soil should not be less than 50 cells. However, they observed that population densities of rhizobia nodulating Mucuna in all the studied soils were less than 50 cells per gram soil. A much greater nodulation (>2x) of Mucuna was achieved when the soil was inoculated with rhizobia. In contrast, the populations of rhizobia nodulating cowpea and green gram were more than 50 cells per gram soil in most of the studied soils. These results may explain why cowpea does not respond to inoculation in most tropical soils (Dogbe et al., 2000; Doku, 1969; Kang et al.,1977). To increase rhizobial numbers and nodulation of some introduced legumes in Ghana, there may be a need for inoculation as shown with the case of Mucuna (Dogbe et al., 2000). Screening for genotypes that will nodulate better under present conditions and/or enhancing the soil conditions may be other possible options. Most of the studies point to the fact that the quantity of N_2 fixed by cover crops may be enough to compensate for the annual loss of N through crop removal in cereal-based cropping systems in Ghana, thus indicating the sustainability of N-use though other nutrients like P, K, Ca and Mg may have to be added in the long-run.

Intercropping effects on crop yields

The main features of the cropping systems in Ghana show that sole cropping is relatively unimportant and cereal-legume mixtures are the most common combinations (Diehl, 1992). Legumes and food crops are often intercropped, either simultaneously or in a relay pattern. This system may be extended to fallow legumes or cover crops by intercropping the fallow cover with food crop cultivation. Similar to rotation fallow, the beneficial effects of relay fallow depend on the N-fixing capacity, plant N content and biomass yield of the intercropped legumes. Nonetheless, Härdter (1988) reported that intercropping of maize and cowpea strongly depressed maize yields compared to yields from rotation plots. The beneficial effect of grain legumes on subsequent maize crop was severely reduced or disappeared altogether when the legumes were intercropped with maize (Schmidt and Frey, 1992). In addition to socioeconomic advantages, including the saving in labor, food diversification and risk insurance, the adoption of mixed cropping by the farmers may also offer technical advantages, including better use of growth factors and soil protection. The legumes in the cropping systems enable farmers to cope with weed infestation, erosion and declining levels of soil organic matter and available N. Better use of natural resources may be possible where component crops differ in their growth habits and thus have different requirements in time and space for optimal growth.

Changes in soil chemical and physical properties as affected by intercropping

Despite claims for substantial transfer of N for grain legumes to companion cereal crops, the evidence indicates that benefits are limited (Härdter and Host, 1991, Schmidt and Frey, 1988). There was no indication of N transfer from legumes to the non-legume crop when the two were intercropped in some studies (Härdter and Host, 1991; Kaleem, 1989; Schmidt and Frey, 1988). Mixed cropping of maize and cowpea shows that the common assumption that a good cowpea crop improves N availability to a companion crop may not always be true. Moreover intercropped maize had lower N concentrations in the ear leaf at silking indicating low N nutrition for maize in maize-cowpea intercropping system. The mineral N remaining in the field at harvest was almost 6, 18 and 50 kg ha^{-1} in maize/cowpea relay intercropping, maize/cowpea mixed cropping and maize-cowpea rotation, respectively. This implies that intercropping of a legume and non-legume may not lead to an improved use of soil and fertilizer N and P or an enhanced N_2 fixation (Härdter and Host, 1991). Rather benefits are more likely to accrue to subsequent non-legume crop in a nonlegume-legume rotation as the main transfer pathway is due to root and nodule senescence and fallen leaves (Härdter and host, 1991; Kaleem, 1989; Ofori and Stern, 1987; Schmidt and Frey, 1992).

Identical quantities of maize and groundnuts grown over a 4-year period in unfertilized rotation resulted in higher soil N levels (36 mg g^{-1} dry matter) than if grown intercropped (33 mg g^{-1} dry matter). Groundnut is generally not the best partner for intercropping with cereals (Koli, 1975; Schmidt and Frey, 1985) and therefore maize-groundnut intercropping must be considered as disadvantageous but maize-cowpea intercropping seems to be advantageous in the year of cultivation only as the residual value seems to be largely lost when compared with that of sole crop cowpea. A similar trend may apply to pigeon pea.

Härdter and host (1991) observed that maize and cowpea proved to be very similar in their use of soil N and they explained that the high N uptake efficiency of cowpea is due to its extensive root growth, which is also responsible for its drought tolerance

(Rachie and Roberts, 1974). In calculating N balance for different cropping systems as affected by N application in northern Ghana, Härdter (1988) observed N losses for all cropping systems except cowpea in rotation with maize only where a positive N balance (32.0 kg N ha^{-1}) was obtained indicating N gains by N_2 fixation. These gains were however, small probably due to the efficient utilization of soil mineral N by cowpea. Total N uptake was similar in both mixed cropping and sole cropping systems, regardless of the fertilizer application, although the total plant population in the mixed cropping system was higher than in the sole cropping and N_2 fixation by the cowpea was expected. These results suggest a competition between maize and cowpea for soil and fertilizer N in the mixed cropping system. Thus the competition has to be considered as a limiting factor in mixed cropping with maize (Härdter, 1989; Härdter and Host, 1991; Horst and Härdter, 1994). In contrast, N uptake among different cropping systems based on only unfertilized plots revealed that N uptake of 35.8 kg N ha^{-1} in maize monocropping was significantly lower than in maize-cowpea rotation (55.2 kg N ha^{-1}), maize-cowpea relay intercropping (55.3 kg N ha^{-1}), maize-cowpea mixed cropping (57.1 kg N ha^{-1}) and cowpea-maize rotation (58.4 kg N ha^{-1}). This may be attributed to the low N mineralization of maize residue in monoculture. The higher N uptake in the mixed cropping system with cowpea may be explained by the subsequent higher N mineralization of the early maturing cowpea residue added to the soil (Härdter and Frey, 1992). The N uptake was not different among the cropping systems where cowpea was included.

Intercropping of grain legumes generally results in the legume deriving a greater proportion of its N from N2 fixation than when grown alone, but legume dry matter production and N accumulation are usually reduced because of competition from the companion crop (Härdter and Host, 1991; Kaleem 1989) so that the overall amount of N2 fixed is less. For example, cowpea fixed less N2 in a mixed cropping system than in the sole cropping system and this was attributed to the lower density of cowpea plants in the mixed cropping system. However, the lower N2 fixation in the mixed cropping after N fertilizer application, which favoured maize growth considerably, indicated a limitation of nodulation and N2 fixation due to the maize component shading cowpea, as shown by Eriksen and Whitney (1984). The application of 80 kg N ha-1 to maize in the mixed cropping system further reduced the nodulation of cowpea roots, which is in agreement with the low N2 fixation in the mixed cropping system (Härdter and Host, 1991). Similarly, high N doses depressed nodulation and N2 fixation in cowpea and common bean (Ofori and Stern, 1987; Safo, 1990) and had depressive effect on groundnut yields due to an increased competition from a companion maize crop (Schmidt and Frey, 1992). However, small additions of N fertilizer to soybean and cowpea may give substantial crop responses due to low N status of the soils in Ghana. Differences in levels of N2 fixation by legumes intercropped with maize have been reported by Kaleem (1989) in northern Ghana where groundnut fixed the greatest amount compared with Bambara groundnut, cowpea or soybean. Moreover, groundnut and soybean derived the greatest proportion of their N from the atmosphere, obtaining 89 and 84%, respectively, when compared with bambara groundnut and cowpea which had less than 72 %. Cowpea intercropping was advantageous when intercropped with maize or millet in seasons with adequate rainfall, but the cowpea competed strongly with the cereal crop for soil water when rainfall was limiting.

Results from alley cropping

One of the most commonly tested tree-based systems is alley cropping, where food crops are grown between hedgerows of trees or shrubs. The hedgerows are pruned to reduce competition and to provide mulch. In general, alley cropping or hedge row intercropping systems are adapted to help not only increase nutrient pools but also help reduce loss of soil organic matter, nutrients and run off. To improve the soil organic matter, several agroforestry trees have been evaluated for their adaptability and biomass production in the Guinea and Sudan savanna zones of Ghana. Earlier studies in the 1980s using *Leucaena leucocephala* as a source of manure in alley cropping in Ghana were never successful because Leucaena seedlings had poor seedling vigor. The poor growth was attributed to either P deficiency and/or unsuccessful rhizobium symbiosis (Sipkens and Diehl, 1992 ; Kaleem, 1992). Kaleem (1992) reported that the failure of *Leucaena leucocephala* and chick pea (*Cicer arietinum*) to nodulate freely in soils of northern Ghana as compared with the free nodulation observed in the other legumes clearly demonstrated specific rhizobium requirements of the two legumes. Leucaena growth was improved after inoculation (Sipkens and Diehl, 1992).. Cropping the two legumes without inoculants application will result in a decline in soil nitrogen status rather than amelioration in northern Ghana (Kaleem, 1992).

Alley cropping has been very useful for developing a better understanding of tree-crop interactions but its applicability in smallholder agriculture still remains to be demonstrated because of strong crop-tree competition and the intensive management required (Sipkens and Diehl, 1992). Intercropping and relay cropping of legume green manures have the advantage that crops are still produced while organic material is produced for soil amendment. The obvious disadvantages are that the green manures or trees may compete with the crops for moisture leading to reduced crop yields (Schmidt and Frey, 1988), and that the amounts of organic material produced are generally less than when the land is devoted to soil improvement.

Surface application of pigeon pea residue to supply 9-65 kg N ha^{-1} did not increase maize grain yields significantly over the control plots without pigeon pea residues. Only Urea applied at 30 kg N ha^{-1} resulted in a yield increase of 200% over the control. The lack of response to pigeon pea residue may have been due to the relatively low rates applied, the late time of application (7-11 weeks after planting) or to surface application instead of incorporation in the soil. Yield increases, however, were obtained when relatively higher rates of pigeon pea prunings (65-155 kg N ha^{-1}) were applied at 3 or 6 weeks after planting maize and incorporated into the soil through weeding. The yields from such high rates were comparable to maize yields from plots that received 30 kg N ha^{-1} as urea. This implies that large quantities of pigeon pea biomass must be applied to get an increase in maize yield. These results corroborate findings by IITA researchers working with Leucaena (Kang et al. 1981). Large quantities of biomass may not be available in on-farm pigeon pea alley cropping. Based on these results, Sipkens and Diehl (1992) concluded that pigeon pea alley cropping does not seem to hold much promise as a means of substituting fertilizer N under the ecological conditions prevalent in the northern region of Ghana.

Yeboah et al. (2004) observed that there is a high potential for pigeon pea as a good vehicle for Mg, K and Na cycling in soils but there was P mining under pigeon pea cultivation where seed grain is harvested. Available P declined by 26% in the cultivated sites. Their data indicated a decline in soil pH with pigeon pea cultivation. Furthermore, the mean organic carbon content of the pigeon pea sites was about 2.5% lower than the mean of the uncultivated sites. The cultivated and uncultivated plots had similar levels of total N but exchangeable cations (except Ca) were higher in the pigeon pea cultivated sites than in the uncultivated sites. Compared with the uncultivated sites, cultivation of pigeon pea also increased exchangeable bases, cation exchange capacity, available K and exchangeable Mg by 5, 5, 25 and 100 %, respectively. More moisture was stored under pigeon pea cultivated sites which also had a higher bulk density (1.40 gcm^{-3}) than the uncultivated site (1.28 gcm^{-3}). With continuous addition of hedgerow prunings, higher organic matter and nutrient status are maintained than on plots receiving no prunings. Alley rows of pigeon pea or Leucaena have caused a severe competition for maize with regard to soil moisture leading to reduced yields in the savanna zone

The amounts of the N in the leaf biomass of different tree species grown in Sudan savanna zone of Ghana are shown in Fig.1 (Nyamekye, 1997). *Cassia siamea* produced significant leaf biomass, about 4.6 t ha^{-1} yr^{-1} dry matter with a potential N accumulation of 80kg N ha^{-1} yr^{-1}. This was followed by *Acacia. auriculiformis* (over 70kg ha^{-1}) and *Albizia lebbeck* (Bawku) with over 40kg ha^{-1}. *Calliandra calothyrsus* produced the lowest amount of N (<10kg N ha^{-1} yr^{-1}). *Leucaena leucocephela* contributed about 15kg N ha^{-1} yr^{-1} as compared to 200kg N ha^{-1} yr^{-1} in the subhumid region of Nigeria (Kang and Duguma, 1985). The amounts of P and K follow similar trends as those of N. The amount of N in the leaf was a function of the leaf dry matter yield of the tree species (Table 11). The results show that various tree species can produce considerable amounts of biomass which contain some major soil nutrients (N, P and K).

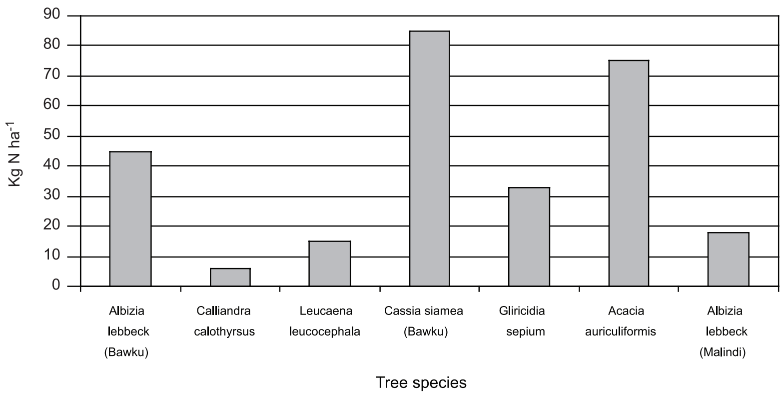

Figure 1. Amount of N in leaf biomass of different tree species in the Sudan savanna zone of Ghana (Source; Nyamekye, (1997)

Table 11. Leaf and stem dry matter yield of tree species at 24 months after planting in the Sudan savanna zone of Ghana

Tree species	Leaf dry matter (kg ha^{-1})	Stem dry matter (kg ha^{-1})
Albizia lebbeck (Bawku)	1192	3193
Calliandra calothyrsus	351	538
Leucaena leucocephala	499	1174
Cassia siamea (Bawku)	4587	7788
Gliricidia sepium-55	1693	2642
Acacia auriculiformis	3729	6802
Albizia lebbeck (Malindi)	437	722
Mean	1784	3257
CV (%)	25.9	53.0
LSD (0.05)	533.5	1174

Source; Nyamekye, (1997).

The traditional agroforestry practice of farmers who maintain trees such as Faidherbia [*Faidherbia albida* (Del.) A. Chev,] and Dawadawa [*Parkia biglobosa*] in their fields is well documented as a means for maintaining fertile islands of soil around the trees. The trees are not planted but retained on purpose. The native leguminous tree called *Faidherbia albida (*formerly called *Acacia albida)* grows in very dry areas of the northern savanna zone. The tree is very deep rooted and is able to extract water that has moved down through the soil that would otherwise be lost. During the rainy season, the Faidherbia drops its leaves and goes into a state of dormancy; thus it does not compete with the growing crop. The leaves of the tree are high in N and the added organic matter beneath the tree facilitates more moisture retention than the surrounding soil. The crops planted under the tree often show much better growth than the crops in the rest of the field. Recognizing of the benefits of this tree, many communities do not cut or harm the Faidherbia tree. There is, however, no experimental evidence to show the effect of these trees on crop yield in Ghana.

Conclusion

In order to meet the growing demand for increased productivity, extra N must be brought into the cropping systems and this can be provided through the use of fertilizers or through addition of fixed N_2. There is no single solution to the problem and interventions need to be tailored to, and developed jointly with farmers with due regard to the wide diversity of farming systems, cultures and needs. At the low levels of N and P in these soils, a production system that will maximize the use of local, biological sources of nutrients, which can be supplemented with mineral fertilizer, stands a better chance of increasing food production on a sustainable basis. The search for substitutes for imported inorganic fertilizer has not been successful. Other soil-fertility measures, especially organic fertilizers and rock phosphate, are complements not substitutes for inorganic fertilizers.

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Chapter 7

Rôle des légumineuses sur la fertilité des sols et la productivité des systèmes de cultures

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Résumé

De nombreux travaux de recherche ont été consacrés au sujet, visant particulièrement à exploiter les légumineuses comme moyen pour améliorer la fertilité et la productivité des systèmes de culture. Il existe certainement beaucoup d'acquis de recherche. Il est nécessaire de faire le bilan des acquis sur le rôle des cultures légumineuses afin de dégager les perspectives éventuelles permettant une meilleure exploitation des légumineuses pour une gestion durable des systèmes de culture. C'est l'objet de cette étude. Les résultats de recherche montrent que par leur capacité à utiliser à la fois l'azote du sol, des engrais et de l'atmosphère, les cultures légumineuses fixatrices d'azote peuvent influencer la fertilité des sols et la nutrition minérales des cultures. Elles fixent des quantités très variables d'azote selon le type de légumineuse, la variété, la nature du sol et les pratiques culturales en général et la fertilisation en particulier. Par leurs résidus riches en azote, elles influencent la quantité et la qualité du carbone organique. Elles peuvent influencer la disponibilité et l'utilisation des certains éléments comme l'azote et le phosphore du sol. Les plantes légumineuses sont généralement moins exigeantes en engrais et valorisent mieux le phosphore peu soluble des phosphates naturels par exemple. Cultivées en rotation ou en association avec les cultures non fixatrices d'azote comme les céréales, les légumineuses peuvent influencer les rendements et la productivité des systèmes de culture. La fertilité des sols et la productivité des systèmes traditionnels peuvent probablement être améliorées à moindre coûts par une gestion intégrée des rotations culturales avec les légumineuses, les amendements agro minéraux locaux (phosphate naturels, dolomie) et les amendements organiques.

Mots clés: *Engrais, Azote, légumineuses, Fertilité, sol,Burkina Faso*

Abstract

Many researches on the role of N_2-fixing legume crops on soil fertility and non-fixing crop yields have been undertaken in the West Africa region during the last years. Interesting achievements have been obtained. A critical review of the main results and suggestions for integrated management of N_2-fixing legume crop and fertilizers for soil improvement are proposed in this paper. Because of their abilities to use three sources of N (soil, fertilizers and atmosphere), N_2-fixing legume crops affected N dynamic. Legume crops such groundnut (*Arachis hypogea*) and cowpea (*Vigna unguiculata*) can fix 8 to 120 kg N ha^{-1} (or 25 to 70% of their total N) from the atmosphere. Crop residues of legumes increase soil organic C and mineral N that improve N absorption and yields of succeeding non-fixing crops. The N fertilizer equivalencies of legumes vary from 25 and 35 kg N ha^{-1}. In Legume-cereal rotations, legumes can increase cereal grain yield from 60 to 300% compared to continuous cereal. While legume yields and biological nitrogen fixation (BNF) is improved by organic agro minerals such as dolomite and rock phosphates, some legumes also improve soil fertility factors such occluded P dissolution and highly insoluble calcium bounded phosphorus by legume root exudates. Soil fertility of smallholder farmer's systems can be improved and low cost management technologies can be developed with integrated management options of N_2-fixing legume crops, organic amendments, local agro mineral resources such as phosphate rock, dolomite combined with the low quantities of mineral fertilizers used by farmers.

Key words: *Fertilizer, Nitrogen, Legume, Fertility, Soil, Burkina Faso*

Introduction

L'agriculture des pays d'Afrique Subsaharienne est caractérisée par sa faible productivité. Les faibles rendements des cultures sont très souvent expliqués par les conditions pluviométriques défavorables et la pauvreté naturelle des sols en éléments nutritifs (Bationo, Mokwunye 1991a). À ces facteurs naturels s'ajoutent les facteurs anthropiques défavorables à la productivité agricole. L'Afrique Subsaharienne connaît une forte croissance démographique entraînant une forte pression sur les ressources en terres cultivables. L'augmentation de la population est accompagnée d'une augmentation du cheptel entraînant du même coup une augmentation de la demande en produits végétaux utiles à l'homme et à l'animal. Il en résulte une forte pression sur le couvert végétal, diminuant la capacité des sols à produire la biomasse nécessaire aux besoins d'une population de plus en plus nombreuse. Dans un tel contexte, la jachère qui était le moyen traditionnel pour restaurer la fertilité des sols est moins pratiquée à cause de cette forte demande en terres cultivables (Sedogo, 1981).

Les engrais minéraux sont principalement importés avec des prix de revient élevés. Ils sont très peu utilisés à cause des faibles revenus des producteurs. Les producteurs africains utilisaient environ 6 kg ha^{-1} d'engrais pendant que la moyenne mondiale était de 80 kg ha^{-1} (McIntire 1986 ; Stoorvogel, Smaling 1990). L'utilisation des engrais organiques est également faible. En fin de saison de culture les résidus de récolte sont à la fois consommés par les animaux transhumants et utilisés par les ménages comme source d'énergie ou pour des utilisations diverses (Bationo, Buerkert 2000). Cette agriculture extensive à très faibles intrants sans recyclage des résidus de récolte entraîne à la longue une exportation des éléments nutritifs et un appauvrissement continu des sols (Bado et al. 1997a, Berger et al. 1987 ; Bationo et al. 1998 ; Bationo, Mokwunye 1991a,b) ; Bado 2002). Caractérisée ''d'agriculture minière'' par la FAO, ce type d'agriculture prélève environ 22 kg N, 3 kg P et 14 kg K par hectare chaque année (Stoorvogel, Smaling 1990).

L'azote et le phosphore sont les deux premiers facteurs limitant les rendements des cultures sur les sols des zones semi-arides d'Afrique de l'Ouest (Bationo et al, 1991a). Cependant, 79% du volume en gaz N_2 de la biosphère se trouve dans l'atmosphère constituant ainsi la principale source d'azote (Haynes 1986; Foth 1990). Les cultures légumineuses fixatrices d'azote offrent des alternatives pour améliorer la fertilité des sols et la productivité des systèmes de cultures. Par leur capacité à fixer l'azote de l'atmosphère grâce au processus de la fixation symbiotique, les cultures légumineuses peuvent améliorer le bilan de l'azote dans les systèmes de cultures (Wani et al. 1995 ; Chalk 1998).

Les producteurs utilisent certaines cultures légumineuses comme l'arachide et le niébé en rotation ou en association avec les céréales. Certains les utilisent comme cultures régénératrices de la fertilité après plusieurs années de monoculture de céréales. On peut assumer qu'un système de cultures utilisant une légumineuse fixatrice d'azote en rotation ou en association, aura probablement un meilleur bilan en azote et une meilleure productivité qu'une monoculture de céréales par exemple. Outre l'azote, certaines légumineuses sont capables d'utiliser des formes de P fortement fixées par les sols (Gardner et al 1981). À l'évidence, le type de cultures influence la micro et macro flore du sol. Les monocultures, les types de rotations et associations de cultures influencent différemment la flore et l'activité microbienne du sol. La présence ou l'absence de légumineuses dans le système de culture peut influencer l'activité biologique y compris certains parasites des cultures comme les nématodes.

Un certain nombre de travaux ont été effectués dans le domaine (Dommergues, Ganry 1986 ; Hardarson, Danso 1993; Danso, 1995; Bagayoko 1999; Bado 2002). Le but de cette synthèse est de faire le point des résultats acquis afin d'identifier les axes pertinents de recherche permettant de mieux valoriser les légumineuses dans les systèmes de culture. Nous ferons d'abord le point des connaissances sur les capacités des légumineuses à fixer l'azote de l'atmosphère. Puis nous évaluerons les acquis sur les effets des légumineuses sur les rendements des autres cultures. Nous évaluerons ensuite les résultats acquis sur leur influence sur l'enrichissement du sol, la nutrition minérale des autres cultures.

La fixation symbiotique de l'azote

De nombreux travaux ont été consacrés à l'évaluation des quantités d'azote fixées par les plantes légumineuses dans l'atmosphère avec de multiples méthodes aussi complexes que variées (Danso, 1995). Malgré la grande variabilité des résultats innérante aux méthodes utilisées, la plante témoin ou plante test (Hardarson, Danso 1993) il est établi que plusieurs cultures légumineuses localement utilisées par les producteurs fixent des quantités non négligeables d'azote provenant de l'atmosphère. Selon Dakora (1985), l'arachide fixerait 32 à 100 kg ha^{-1} d'azote, correspondant à 62 à 84% de ses besoins en azote quand on utilise la méthode de la différence d'azote. Par la méthode de la dilution isotopique, d'autres travaux (Rusli et al. 1998 ; Bado 2002) indiquent que l'arachide fixerait environ 10 à 16 kg ha^{-1} dans l'atmosphère soient 37 à 47% de son azote total. Le niébé fixerait environ 20 à 46 kg ha^{-1} d'azote, correspondant à 37 à 67% de ses besoins en azote quand on utilise la méthode de la différence d'azote (Bado 2002). D'autres auteurs (Dommergues, Ganry 1986 ; Senaratne et al. 1998) ont montré que le niébé pouvait fixer des quantités d'azote plus élevées allant jusqu'à 50 à 75% de ses besoins en azote par la fixation symbiotique. La variabilité des résultats pour une même légumineuse provient essentiellement des méthodes utilisées, les variétés et les facteurs liés à l'environnement (sol, pluviométrie) (Hardarson, Danso 1993 ; Khan, Yoshida1994 ; Danso 1995 ; Trytsman Smith 1998). La nature du sol influence la fixation symbiotique de l'azote et on peut améliorer les capacités des plantes à utiliser l'azote atmosphérique par des techniques de fertilisation appropriée (Tableau 1). La croissance, la production de biomasse et les rendements sont les premiers indicateurs de l'état nutritionnel des plantes. Ce sont des indicateurs de la disponibilité des éléments nutritifs et de leur utilisation par la plante. En fait, la disponibilité des éléments nutritifs et la capacité d'une légumineuse à fixer l'azote sont deux facteurs liés. Dans un sol, les rhizobia et la plante hôte disposent des éléments nutritifs qui leur sont nécessaires pour initier et entretenir l'activité symbiotique conduisant à la fixation de l'azote. Une déficience quelconque en éléments nutritifs peut diminuer le développement de la plante, des rhizobia et l'activité symbiotique, d'où une faible fixation de l'azote (Khan, Yoshida 1994). Le phosphore améliore en particulier la fixation symbiotique de l'azote et beaucoup de travaux indiquent que l'efficacité du P sur la fixation de l'azote réside dans sa capacité à augmenter la nodulation et l'activité de la symbiose (Olofintoye 1986; Giller et al. 1995). Les effets bénéfiques de la dolomie, du fumier et du phosphate naturel peuvent s'expliquer par leur double rôle sur la fertilité et la structure du sol. Ils améliorent l'activité symbiotique en apportant également des éléments nutritifs pour les rhizobia et les légumineuses. Les éléments P, Ca, Mg et Mo semblent être les principaux éléments nutritifs limitant la productivité des légumineuses dans la zone tropicale semi-aride de l'Afrique de l'Ouest (Singh et al. 1985 ; Bationo et al. 1991a ; Bationo, Ntare 2000).

Tableau 1: Quantités d'azote fixé par l'arachide et le niébé dans l'atmosphère selon les types de fumures utilisées à Farakô-Ba (Burkina Faso).

	Fumures (kg ha^{-1} d'éléments nutritifs)	Total N (kg N ha^{-1})	Ndfa (kg N ha^{-1})	Ndfa (%)
Arachide	NPK (14-10-11)	27 [cd]	-	-
	NPK (14-10-11) + Dolomite (249 Ca^{++}, 114 Mg^{++})	34 [ab]	15 [ab]	43 [ab]
	NPK (14-10-11) + Fumier (552 C, 54 N, 9 P, 5 K)	35 [a]	16 [a]	45 [a]
	NK (14-11) + Phosphate naturel (10 P)	26 [c]	10 [c]	37 [c]
	Moyenne	31	14	42
Niébé	NPK (14-10-11)	53 c	20 [d]	37 [d]
	NPK (14-10-11) + Dolomie (249 Ca^{++}, 114 Mg^{++})	63 [ab]	40 [ab]	62 [ab]
	NPK (14-10-11) + Fumure (552 C, 54 N, 9 P, 5 K)	68 [a]	46 [a]	67 [a]
	NK (14-11)+Phosphate naturel (10 P)	50 [cd]	22 [c]	43 [c]
	Moyenne	58	32	52

Ndfa : Azote provenant de l'atmosphère

Les valeurs affectées d'une même lettre dans la même colonne ne sont pas significativement différents ($p<0.05$) selon le test de Fisher

La fixation symbiotique de l'azote est mesurée par la méthode de la dilution isotopique avec le ^{15}N (ammonium sulfate à 10% excès atomique).

Source: Bado (2002)

Légumineuses et rendements des cultures

Les cultures légumineuses comme le niébé ou l'arachide cultivées par les producteurs fixent des quantités importantes d'azote provenant de l'atmosphère (Tableau 1). Si cet azote est recyclé dans le système, il devrait entraîner un certain surplus de rendement sur les autres cultures. On peut se poser la question de savoir si l'azote d'une légumineuse contribue à la nutrition d'une culture qui lui succède.

De nombreux travaux ont tenté d'évaluer les effets des légumineuses sur les rendements des autres plantes cultivées en rotation ou en association avec les cultures non fixatrices d'azote. Les effets bénéfiques des précédents légumineuses ont été démontré par plusieurs travaux (Stoop, Staveren 1983; Bagayoko et al. 2000; Bationo, Ntare 2000; Bado 2002). La plupart des travaux montrent que les effets de la légumineuse sont remarquables après 2 à 3 années. Les données de deux expérimentations de longue durée conduites à Saria (Pichot et al. 1981; Sédogo 1981; Pieri 1989) et Kouaré (Bado 2002) dans la zone soudanienne du Burkina démontrent clairement que lorsqu'il est cultivé en rotation avec le niébé, le sorgho produit des rendements toujours supérieurs à ceux de la monoculture (Figures 1 et 2). Les effets bénéfiques des légumineuses sont observables même en l'absence d'engrais (Figure 1) et quelques soit le type de fumure utilisée. Très souvent, les effets des légumineuses sont même observables dès la seconde année de culture (Figure 2), et elles peuvent augmenter les rendements de la culture suivante de 70 à 100% comparativement à la monoculture (Bationo, Ntare 2000 ; Carsky et al. 2001; Bado 2002).

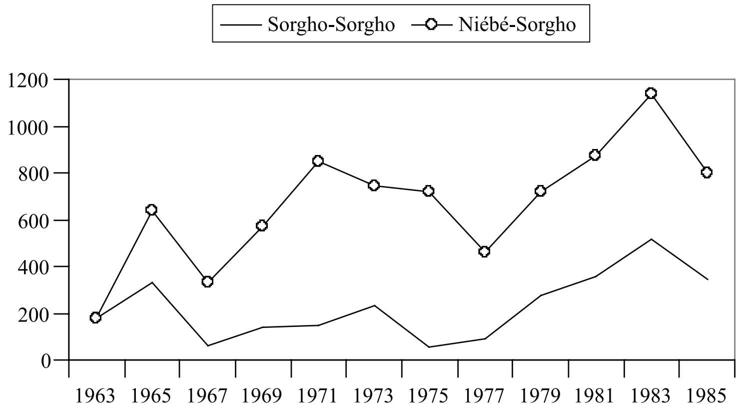

Figure 1: Effet de la rotation niébé-sorgho sur les rendements du sorgho comparativement à la monoculture pendant 22 années (1963-1985) à Saria, Burkina Faso.

Source : Adapté de Sédogo (1981)

Mais les effets des légumineuses sont souvent variables selon le type de légumineuse utilisée. Il été souvent observé que parmi les légumineuses couramment utilisées, le niébé semble être le meilleur précédent cultural (Bagayoko et al. 2000 ; Bationo, Ntare 2000 ; Bado 2002). Il est par exemple plus efficace sur les rendements du sorgho que l'arachide et ce quelque soit le type de fumure utilisée. Mieux, les fumures stimulent davantage les effets des légumineuses (Bado 2002).

Les courtes jachères (2 à 3 années) ont été étudiées comme alternative pour améliorer la fertilité des sols. À titre de comparaison, on peut se poser la question de savoir si les jachères courtes sont plus efficaces que la simple rotation annuelle avec une légumineuse. Autrement dit, le producteur aurait-il intérêt à pratiquer la jachère de courte durée (sorgho-jachère ou sorgho-légumineuse) par exemple. Selon des travaux recents effectués sur deux sites pendant 6 et 11 années successives (Bado 2002), les rotations bi ou tri annuelle (sorgho-légumineuse ou coton-sorgho-légumineuse) donnent de meilleures rendements en sorgho et en coton que les rotations avec la jachère de courte durée. Certes, comparativement à la monoculture, une rotation jachère-sorgho peut permettrre de doubler par exemple les rendements du sorgho. Mais ces essais de longue durée ont revelé que les rotations avec l'archide ou le niébé permettaient de tripler ou même de quatrupler les rendements de la culture venant après la légumineuses. Ainsi, une rotation Jachère-céréale produit des rendements plus élevés que la mono culture mais elle demeure moins efficace qu'une rotation légumineuse-céréale. De plus, la rotation avec la jachère présente l'inconvenant de perdre une saison de récolte sur la parcelle en jachère.

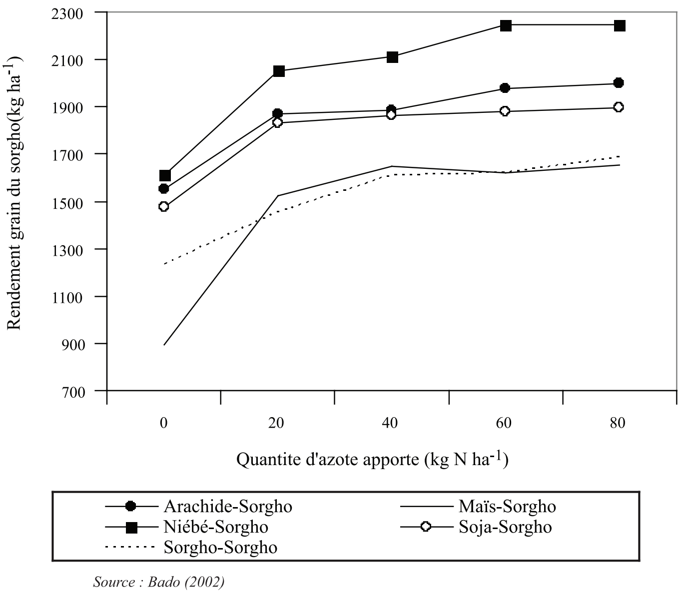

Figure 2: Influence des rotations avec l'arachide, le niébé, le soja ou le maïs sur la réponse du sorgho aux applications d'engrais azoté.

Source : Bado (2002)

Légumineuses et nutrition azotée

Les effets bénéfiques des légumineuses sur les rendements des autres cultures sont incontestables. Ils ont été bien démontrés et quantifiés (Bagayoko 1999 ; Bationo, Ntare 2000 ; Bado 2002). Il importe surtout de chercher plutôt à comprendre les processus expliquant ces effets afin d'étudier les voix possibles pour les améliorer. En général les chercheurs établissent une relation de cause à effet entre l'azote fixé par les légumineuses et les augmentations de rendements des cultures succédant aux légumineuses. La culture succédant à la légumineuse profiterait indirectement de l'azote provenant de la fixation symbiotique (Chalk 1998). C'est en suivant et en quantifiant les effets azote dans les éléments du système (atmosphère, légumineuse, sol, plante) que l'on peut éventuellement comprendre le rôle joué par les légumineuses dans les augmentations des rendements.

Toute plante utilise les éléments nutritifs du sol pour assurer sa croissance. À la différence des plantes non fixatrices, les légumineuses utilisent à la fois l'azote du sol et de l'atmosphère. Elles devraient en principe influencer différemment la richesse du sol en azote en prélevant peut-être moins d'azote que les plantes non fixatrices. Par leur capacité à prélever l'azote de l'atmosphère, les légumineuses contribuent peut-être à enrichir le sol en azote. En fixant de l'azote de l'atmosphère et en prenant moins d'azote dans le sol, la légumineuse influence d'une certaine façon la dynamique global de l'azote dans le système. Cet effet de la légumineuse est souvent désigné par le terme « effet azote ». Il peut être évalué en mesurant l'azote disponible dans le sol après la culture de légumineuse ou par l'estimation de l'azote global absorbé par la plante succédant à la légumineuse (Chalk 1998).

Azote minéral du sol

Un bon indicateur pour évaluer la disponibilité de l'azote utilisable par la culture succédant à une légumineuse est l'azote minéral en début de saison pluvieuse. Barrios et al. (1998) ont démontré que l'azote minéral du sol était à l'origine de 60% des variations des rendements des cultures après une culture de légumineuse. La présence des légumineuses augmente l'azote minéral du sol (Baldock et al. 1981; Barrios et al. 1998 ; Bagayoko et al. 2000 ; Bationo, Ntare 2000 ; Bloem, Barnard 2001 ; Bado 2002). À titre de comparaison, certains résultats indiquent que les sols des rotations comportant des légumineuses libèrent plus d'azote minéral que les monocultures de céréales ou les rotations avec les jachères de courte durée (Bado 2002). Même si la jachère annuelle peut augmenter l'azote minéral de 25% la saison suivante, un précédant arachide ou niébé peut augmenter l'azote minéral de 40 à 50% par rapport au sol sous monoculture de sorgho (Shumba 1990 ; Bado 2002).

L'augmentation de l'azote minéral dans les rotations légumineuses-céréales peut s'expliquer par les résidus de récoltes recyclés dans le sol. Même si une grande partie des fanes des légumineuses est exportée, une partie non négligeable de feuilles et des parties souterraines est recyclée dans le sol. À quantité égale, les résidus des légumineuses sont plus riches en azote et se décomposent plus vite que ceux du sorgho. Ils recyclent certainement plus d'azote dans le sol comparativement aux résidus de sorgho. Ainsi, dans la rotation légumineuse-céréale l'azote fixé dans l'atmosphère par la légumineuse, peut contribuer indirectement par le recyclage des résidus à augmenter l'azote disponible dans le sol (Varvel, Peterson 1990). Les deux mécanismes (économie d'azote et recyclage des résidus des légumineuses riches en azote) peuvent justifier les quantités plus élevées d'azote minéral dans les rotations légumineuses-céréales.

Recouvrement de l'azote

En augmentant la disponibilité de l'azote dans le sol (N minéral) les légumineuses devraient influencent l'absorption de l'azote par les plantes succédant aux légumineuses. On a souvent constaté que les quantités d'azote prélevées par les plantes succédant aux légumineuses sont généralement supérieures à celles prélevées par les monocultures de plantes non fixatrices (Bado, 2002). Un précédent niébé peut par exemple augmenter l'azote prélevé par le sorgho de 35% comparativement à la monoculture (Table 2). Une analyse des sources d'azote par les techniques isotopiques révèlent que cette augmentation de la nutrition azotée s'explique par une meilleure utilisation de l'azote provenant de deux sources : le sol et l'engrais (Tableau 2). Comparativement à la monoculture, la plante succédant à la légumineuse prend plus d'azote aussi bien dans le sol que dans l'engrais. Dans les rotations céréales-légumineuses, il y a donc une meilleure utilisation et une bonne réponse de la céréale aux engrais azotés, ce qui expliquent les rendements plus élevés (Varvel et Peterson

1990; Bado 2002). Un précédent arachide ou niébé équivaudrait à une application de 25 à 30 kg N ha^{-1} d'engrais azoté sur le sorgho venant après la légumineuse et une monoculture de sorgho appauvrit 4 à 5 fois plus le sol en azote comparativement à une culture légumineuse (Bado 2002). Cet effet dit ''effet économie d'azote'' par les précédents légumineuses a été bien illustré par Chalk (1998) qui l'interprète comme un effet indirect de la fixation symbiotique qui dans le système de rotation permet à la légumineuse d'utiliser en grande partie l'azote de l'atmosphère et à la céréale non fixatrice d'azote d'utiliser principalement l'azote du sol et des engrais.

En plus de leurs effets azote, les légumineuses peuvent influencer l'infection du sol et des cultures par les nématodes parasites. Il a été observé que le niébé augmente par exemple l'infection du sol par les nématodes (Riekert, Henshaw 1998; Bado 2002). À l'inverse, l'arachide diminue la population des nématode (Bagayoko 1999; Diop et al. 2000; Bado 2002). Alvey et al. (2001) indiquent que le précédent arachide peut diminuer de 60 à 80 fois l'infection du sol par les nématodes comparativement à la monoculture de céréale. La diminution des nématodes par l'arachide serait probablement liée à la nature des composés provenant des résidus de cette légumineuse. Les nématodes ont une affinité pour certaines plantes. Par contre, les résidus et les exsudats racinaires de certaines plantes sont antagoniques au développement des nématodes (Richard, Sayre 1971). Selon Bagayoko (1999), l'arachide ne serait pas un hôte favorable pour les nématodes parasites du sorgho. La réduction des nématodes peut contribuer à l'augmentation des rendements de la culture venant après l'arachide. Par la différence de rendement produit, cet effet sur les nématodes peut être comptabilisé par erreur comme un effet azote.

Tableau 2: Effets des rotations jachère-sorgho, niébé-sorgho et sorgho-sorgho sur l'azote total absorbé par le sorgho, l'efficacité d'utilisation de l'azote de l'engrais (EUN) et l'azote provenant du sol (Ndfs) et de l'engrais Ndff) à Kouaré, Burkina Faso.

Rotations culturales	Total N absorbé (kg N ha^{-1})	EUN (%)	Ndff (kg ha^{-1})	Ndfs (kg ha^{-1})
Jachère-Sorgho	31^{b}	26^{a}	10^{a}	21^{b}
Niébé-Sorgho	48^{a}	22^{ab}	8^{ab}	40^{a}
Sorgho-Sorgho	26^{c}	17^{c}	6^{bc}	20^{bc}

Les valeurs affectées d'une même lettre dans la même colonne ne sont pas significativement différents ($p<0.05$) selon le test de Fisher

Source: Bado (2002)

Rôles des légumineuses dans la nutrition minérale

De nombreux travaux de recherche ont démontré et expliqué comment les légumineuses influencent la nutrition minérale en générale et la nutrition azotée pour affecter la fertilité des sols et les rendements des cultures. Une revue des nombreux travaux a été faite par Peoples et al. (1995).

La première voie expliquant l'efficacité des légumineuses est celle de l'azote (Bullock 1992; Peoples, Crasswel 1992; Peoples et al. 1995). Alors que les cultures non fixatrices utilisent uniquement l'azote du sol, des cultures fixatrices comme l'arachide et le niébé peuvent prélever 30 à 60% de leur azote dans l'atmosphère. Le sorgho prélève par exemple 4 à 5 fois plus d'azote dans le sol que le niébé ou l'arachide. Par le processus de la fixation symbiotique, les légumineuses mobilisent l'azote de l'atmosphère et une quantité importante des résidus des légumineuses (parties souterraines et autres résidus) est annuellement recyclée dans le sol, constituant une source d'azote organique pour la culture suivante. Ainsi les légumineuses augmentent les propriétés physico chimiques et biologiques des sols en général (Alvey et al. 2001) et surtout l'azote minéral par la décomposition de leur biomasse organique qui elle-même augmente l'efficacité d'utilisation de l'engrais azoté par les cultures (Bado 2002).

En plus de l'azote, les légumineuses augmentent la nutrition phosphatée. Par leurs apports en résidus organiques riches en N et P et la solubilisation du P par leurs exsudats racinaires (Gardner et al. 1981) les précédents légumineuses augmentent la nutrition phosphatée des cultures succédant aux légumineuses. Certes, les différents facteurs influencent à des degrés divers les rendements des cultures et permettent de mettre en évidence le rôle des légumineuses sur la fertilité du sol et les rendements des cultures même s'il n'est pas facile d'isoler et quantifier le rôle de chaque facteur.

Les légumineuses peuvent aider à mieux valoriser les faibles quantités d'engrais utilisées par les producteurs si l'on exploite efficacement leur capacité sur la mobilisation de l'azote dans le système (Adrew 1977). Dans les systèmes de rotation utilisant les légumineuses, les ressources agro minérales comme les phosphates naturels et la dolomie peuvent être mieux exploitées comme fertilisants (Sédogo et al. 1991; Bado 2002). Le phosphate naturel peut être utilisé comme source de phosphore. Le phosphore moins soluble (mais moins cher) des phosphates naturels peut être mieux valorisé par les légumineuses, utilisant les formes peu solubles de phosphore. Par les apports de calcium et magnésium utiles à la fixation symbiotique de l'azote, la dolomie peut améliorer aussi bien les rendements des céréales (Bado et al. 1993) que ceux des légumineuses et les quantités d'azote provenant de l'atmosphère et recyclée dans le sol.

Conclusion

Les résultats de recherche suggèrent des stratégies de gestion permettant de mieux valoriser les légumineuses dans les systèmes de culture. Comme on le sait, la faible productivité des systèmes traditionnels est due à la faible utilisation des intrants par les producteurs. En général, les producteurs appliquent très rarement les engrais minéraux sur les céréales ou quand ils le font, ils utilisent de faibles doses souvent très inférieures à celles recommandées à cause de leurs faibles revenus. La simple rotation biennale avec l'arachide ou le niébé sans aucun apport d'engrais azoté permet de doubler le rendement couramment obtenu en milieu paysan. On peut même tripler ce rendement par les rotations avec les légumineuses en y ajoutant une faible dose d'engrais. Des stratégies de gestion intégrée utilisant judicieusement de faibles doses d'engrais, les amendements organiques et minéraux en association ou en rotation avec les légumineuses peuvent permettre d'améliorer la productivité des systèmes traditionnels.

L'utilisation des légumineuses dans les systèmes de culture comporte beaucoup d'autres avantages. L'arachide et le niébé sont des cultures de rente pouvant rapporter des revenus financiers aux producteurs, leur donnant ainsi les moyens d'acheter les engrais. Les fanes des légumineuses constituent un fourrage pour les animaux. Dans un système de production intégrant l'agriculture et l'élevage, l'utilisation des légumineuses permettra d'améliorer la productivité du système. Au champ, les légumineuses amélioreront la fertilité du sol, entraînant une plus grande production de biomasse. Les fanes des légumineuses serviront à l'alimentation des animaux, produisant un fumier riche en éléments nutritifs. Un tel système permettra un recyclage des éléments nutritifs assurant une gestion durable de la fertilité des sols. Mieux que la pratique traditionnelle de la jachère qui est de moins en moins envisageable avec la forte pression sur les terres cultivables, les légumineuses offrent des alternatives plus intéressantes pour une exploitation continue et à long terme de la fertilité des sols.

Quand les moyens du producteur le permettent, l'utilisation des engrais améliore davantage la productivité des systèmes. La dose d'engrais azoté actuellement recommandée pour le sorgho (37 kg N ha^{-1}) est par exemple mieux valorisée si le producteur adopte les rotations Légumineuse-Sorgho avec des augmentations de rendements allant de 150 à 200%. La productivité des systèmes de culture est encore améliorée par des apports complémentaires d'amendements organiques, la dolomie ou avec le phosphate naturel. Dans une rotation biennale légumineuse-céréale, on peut utiliser par exemple la dolomie ou les amendements organiques (fumier, compost) sur la céréale (une année sur deux) et le phosphate naturel sur la légumineuse. Avec leur double avantage par les apports d'éléments nutritifs et la neutralisation de l'acidité, le fumier, la dolomie et le phosphate naturel augmenteront à la fois les rendements de la céréale et la fixation symbiotique de l'azote par les légumineuses, améliorant davantage le bilan de l'azote dans le système. Des courtes jachères améliorées avec des légumineuses annuelles ou pérennes sont des alternatives pour maintenir la fertilité des sols. Judicieusement exploitées, les légumineuses aideraient les producteurs à gérer durablement la fertilité des sols et la productivité de leurs systèmes. Ainsi, différentes options de gestion intégrée peuvent être développées comme outils de gestion durable de la fertilité des sols en utilisant les cultures légumineuses.

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Chapter 8

Soil and water conservation in Ghana: practices, research and future direction

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Abstract

Ghana is an agro-based country with the industry employing about 70% of the total population. Its food production is heavily dependent on rain-fed agriculture by small-scale farmers, making soil and water conservation important to food security in the country. This study provides an overview on types and causes of land degradation and the different conservation practices used by farmers in the country. Water erosion is the main cause of soil degradation that is enhanced by bush burning, overgrazing and poor soil management practices. It also reviews some of the interventions by extension staff, through the use of earth and stone bunds, ridges, beds and mounds. The focus is to provide an overview of research work that has been carried out in Ghana to address problems of soil degradation. Evident from the review is the fact that leaving the soil bare accelerates land degradation. The most efficient way of conserving soil in Ghana as observed by some authors is through mulching and ridging across slope. Also, it is noteworthy that soil conservation work in Ghana lacks coordination and it is yet to address the social, political and economic issues that constraints good conservation practices. Constraining good soil management practices in Ghana are poverty, poor land tenure system and lack of awareness of the benefits of good soil management and the long-term repercussion of soil degradation. The future of soil and water conservation in the country must be handled from both the technological and regulatory perspective.

Key words: *Soil degradation, conservation practices, extension services, Ghana*

Résumé

Le Ghana est un pays basé sur l'agriculture, avec l'industrie employant environ 70% de la population entière. La production alimentaire est essentiellement dépendante de l'agriculture de saison pluvieuse pratiquée par les paysans et faisant de la conservation des eaux et des sols, le principal facteur de sécurité alimentaire dans le pays. Cette étude donne un aperçu sur les types et les causes de dégradation des sols ainsi que les différentes pratiques de conservation des sols utilisées par les paysans dans le pays. L'érosion hydrique est la principale cause de dégradation des sols. Elle est accentuée par les feux de brousse, le surpaturage et les mauvaises pratiques de gestion des sols. L'étude passe aussi en revue les pratiques de conservation des eaux et sols développées par les agents de terrain a travers la confection de cordons en terre ou en pierres, des billons et des buttes. L'objectif de cet article est de fournir un apercu des travaux de recherche menés au Ghana pour trouver des solutions aux phénomenes de dégradation des sols. Il est évident que la non-exploitation des terres accélère la dégradation des sols. La méthode la plus efficace pour la conservation des sols au Ghana, comme l'ont mentionné certains auteurs, est la technique de paillage et de confection de buttes le long des pentes. L'étude relève aussi que les travaux sur la conservation des sols au Ghana manquent de coordination et qu'il est temps de résoudre les problèmes sociaux, politiques et économiques qui limitent les bonnes pratiques de conservation des sols. La paauvreté, le système foncier, le manqué de conscience des avantages des bonnes pratiques de gestion des sols et la répercussion á long terme de degradation de sol sont des constraints de bonne gestion des sols au Ghana. L'avenir de la conservation des eaux at des sols dans le pays doit être contrôlé de la perspective tecnologique et régulatrice.

Mots clés: *dégradation des sols, pratiqués de conservation, services de vulgarization, Ghana*

Introduction

Most soils in Ghana are of low inherent fertility (Acquaye, 1986) and its nutrient retention is poor due to the dominance of low activity clay and low organic matter content. Most parts of the country have degraded soils that continue to degrade. The country continues it downward trend in its negative nutrient balance. With a nutrient depletion rate of 57 kg ha^{-1} of nutrient fertilizer in Ghana (Stoorvogel and Smalling, 1990) soil degradation is eminent. The average estimated nutrient balance of Nitrogen (N), Phosphorus (P) and Potassium (K) (kg ha^{-1} yr^{-1}) were -30, -3 and -17 in 1984 and was expected to decline to -34, -4 and -20, respectively, in 2000 (Stoorvogel et al., 1993). These negative rates are higher than that of Benin and Senegal, all in the West African Sub-region. About 85% of African farmland had nutrient mining rates of more than 30 kg ha^{-1} nutrients (NPK) per year and 40% had rates greater than 60 kg ha^{-1} yearly in 2002-2004 (Henao and Baanante, 2006).

The increasing population pressure on land and food requirements have in recent years led to the extension of cropping areas and lengthening of cropping period. In the period 1971-1986 Ghana recorded a 14% increase in arable land and 11% decrease in forest and woodland (Sant'Anna, 1989). Several thousand hectares of once biologically fertile land have become unproductive, natural waters are polluted, surface water storages are depleted and streams dry up more rapidly with attendant human survival problems (Adu, 1972; Halm and Asiamah, 1986). Soil erosion, the main contributor to land degradation in Ghana is said to be as old as farming. The disastrous effects of accelerated erosion were noticed several decades ago, particularly in northern Ghana (Lynn, 1937) and have become a major issue for policy makers, research scientists, agricultural planners and development workers. As far back in 1971, the Soil Research Institute (SRI) of Ghana outlined the extent of erosion in the country. About 29.5% of the country was estimated to experience slight to moderate sheet erosion, 43.3% severe sheet and gully erosion and 23% very severe sheet and gully erosion (SRI, 1971).

Some of the recognizable features of degraded land in Ghana; include thin topsoil mixed with subsoil gravel, exposed bedrock and roots of trees on uplands and large clay deposits in the downstream section of valleys (Antwi et al., 1998). The direct effect of erosion could be on the site where the erosion originates or on any other site apart from where soil displacement took place, referred to as the off-site effect (Bonsu and Quansah, 1992). Soil erosion results in on-site physical loss of the topsoil that contains most plant nutrient, decrease soil depth and cause soil fertility erosion or decline (Ellison, 1950), as Nitrogen, Phosphorous, Potassium and organic matter are lost (Quansah and Baffoe-Bonie, 1981; Quansah et al., 1997b). At the off-site the damaging effects of erosion may include burying of growing crops, burying of fertile soil, pollution of river bodies resulting from chemicals contained in eroded soil (Quansah, 2000).

Important to solving the continuing degradation problems is first identifying sound technologies that conserve soil and water in the prevailing socio-economic conditions are required for implementation. To address this, a review of indigenous conservation practices, research and extension work on soil and water conservation in the country is provided and suggestions for further improvement also given.

Climate, vegetation and soils of Ghana

The country is divided into six ecological zones based on precipitation and vegetation. These are the Rainforest (>1750 mm), Semi-deciduous forest (1500-1750 mm), Forest-savanna transition (1250-1500 mm), Guinea savanna (1100-1250 mm), Sudan (700-1100 mm) and Coastal savanna (600-1250 mm). The rainfall pattern is mono-modal in the Guinea and Sudan savanna and bi-modal in the remaining ecological zones. There exists considerable variation in rainfall intensity across the country.

Ghana can be put into two broad agro-ecological zones, i.e. savanna and forest. The savanna zone comprises of the Guinea savanna covering most of Northern Ghana, the Sudan savanna covering the north eastern corner of the country and the Coastal savanna in the south eastern part of the country. The dominant tree species in this zone include *Daniella oliveri*, *Lophira alata*, *Guiera senegalensis*, *Combretum glutinosum*, *Vitallaria paradoxa* and *Parkia biglobosa*. The grasses are mainly *Andropogon spp.*, *Pennisetum spp.*, and *Cymbopogon spp.* The forest zone consists of the Rainforest in the southwestern corner of the country and the Semi-deciduous forest covering the major part of southwestern area and a narrow corridor along the eastern border with Togo. Between these two broad categories of agro-ecological zones is the Forest-savanna transitional zone. The high forest is characterized by a *Cynometra-Lophira-Tarretia spp*. association; and moist semi-deciduous forests containing *Triplochiton scleroxylon* and *Celtis spp*.

The vegetation types in the Guinea and Sudan savanna zones are more susceptible to land degradation such as unsustainable farming practices and removal of vegetation cover (e.g. deforestation and overgrazing). Annual bush fire since early 1980's have been a key factor influencing the degradation of vegetation in Ghana.

Soils in Ghana are highly erodible due to their weak structure, low organic matter content and the predominance of kaolinitic clay that makes them prone to erosion. Table 1 gives the main soil types in the country and their main characteristics.

Table 1: Soils of Ghana, their location and main characteristics

Local classification	FAO-UNESCO classification	Area (km^2)	Main characteristics
Forest Oxysol	Ferralsols[1] Acrisols[1, 2]	6478	Deeply weathered, low CEC, acidic
Forest Ochrosol	Luvisol[2] Acrisols[2] Cambisol[2]	31446	Moderate to very deep, dark brown, good water holding capacity
Forest Gleisols	Gleysols[1,2] Fluvisols[2]	5910	Dark grey to grey, mottled brown to reddish brown, imperfectly to poorly drained
Savanna Ochrosol	Acrisols[3,4] Nitisols[3,4] Cambisols[3] Luvisol[4] Plinthosols[3,4]	57300	Strong brown to red, strong to moderate acidity, low CEC, low organic matter
Savanna Gleisols and Alluvisols	Gleisols[4] Fluvisols[4,5] Cambisols[4,5]	17280	Very deep, grey, strongly mottled, non gravelly, imperfectly to poorly drained
Groundwater laterites	Gleysols[4] Luvisols[4]	26936	Shallow to deep plinthite, grey mottled brown to reddish brown, sandy to silty clay, moderately acid in the topsoil
Black clays	Vertisols[5]	2130	Heavy clay, contract and expand with moisture changes, deep wide cracks when dry
Grey earths	Lixisols[5]	3700	Grey to brown, deep, porous, sandy and sandy loam, hardpans in subsoil

Superscript indicates the ecological zone where it is predominantly found [1]Rainforest, [2]=Semi-deciduous forest, [3]Forest-savanna transition, [4]Guinea and Sudan savanna and [5]Coastal savanna

Source: Asiamah (1987); Bonsu et al. (1996)

Types and causes of soil degradation in Ghana

Land degradation as defined by Dudal (1981) is the temporary or permanent (i.e. partial or total) loss of land productivity, quantitatively or qualitatively, through various processes such as erosion, wind blowing, salinization, water logging, depletion of nutrient, deterioration of soil structure and pollution.

Though, natural factors form the basis of most degradation their effects are enhanced by human induced factors. Human factors were outlined by Bonsu et al. (1996) in detail for different ecological zones of the country. In summary they include continuous cropping without good management, crop residue removal and or burning after harvest, annual bush burning, overgrazing, cultivating up-down slope, short fallow periods, excessive wood harvesting for fuel wood and charcoal burning. In northern Ghana, for instance, the combined effect of prolonged dry seasons, high intensity rains, overgrazing, uncontrolled bush burning and poor farming practices promote soil erosion that contributes to soil degradation (Adu, 1972). Prolonged periods without vegetative cover after crop harvest exposes soil to further degradation.

Mechanized farming has the advantages of timeliness of operation, expansion of farm area, convenience of land preparation that improves crop production profitability. However, lack of knowledge on proper operational methods and improper use of tillage implements has made tillage practices one of the key contributors to land degradation. Such improper use of tractors usually leads to soil loss and damage of soil structure. According to farmers and Ministry of Food and Agriculture (MoFA) extension staff the main problem is the setting of plough disc too deep and ploughing along slopes (COWI and PAB Consult, 1995). Tractor plough implements can compact the soil just below the plough depth and also through slipping of worn out tyres on wet soils. Also tractor, that are too heavy are not suitable for a given soil type and moisture condition can lead to soil compaction, When harrowing is carried out in dry soil, the soil is pulverized to dust making it susceptible to leaching, erosion and surface crusting under heavy rains. High intensity rains are responsible for the compaction of bare soil surfaces leading to crusting with a consequent reduction in infiltration rates and accumulation of runoff water.

Organic materials are often not available in the required quantities to maintain good soil organic matter content. Where available the drudgery involved in its transport to the farm makes it use prohibitive. Plant residue is often constrained by burning, and other competing uses such as fuel for cooking and for building purposes. Problems associated with the country's land tenure system and the reduced fallow period (2-3 years) resulting from population pressure has made the practice of shifting cultivation inefficient in sustaining soil productivity.

Indigenous soil and water conservation practices

Soil and water conservation is the promotion of optimum use of land in accordance with its capability so as to assure its maintenance and improvement (Dudal, 1981). Soil conservation is usually carried out to avoid or reverse erosion and other forms of soil degradation. It involves the application of measures to restore degraded soils and prevent them from further damage, and adopting sound soil management methods that yields sustained satisfactory production (Quansah, 2000). Quansah (2000) outlined the different soil management technologies, giving guidelines for their selection and the risk associated with each method.

Most soil and water conservation approaches are on landuse and farming systems, land preparation and agronomic methods. There are many practices that farmers in the country have adopted, which promotes soil and water conservation. These include compound farming, farming around homestead using household waste and farmyard manure, stone terraces and bunds, contour earth bunding, ridging, tied-ridging, cereal-legume intercrop and rotation, and composting.

Apart from earth bunding for water harvesting and in recent times stone bunds and terrace in the Upper East region and the Bunkprugu-Yinyoo district of northern Ghana, physical structures for soil and water conservation are very few. In recent times, the use of vegetative barrier that slows down runoff, spreads it and allows it time to infiltrate and filter through soil particles has been used. Some of the indigenous conservation includes:

Beds: The bed systems when used are usually staggered in the different direction across the slope. It impedes the flow of runoff and therefore improves water infiltration and reduces soil loss.

Stone bunds and terraces: In stony areas, mostly in the Upper East Region of the country stone bunds are built to trap soil and water for crop production. The stones are lined along contours to form a stone bund or arranged to create a terrace (Antwi et al., 1998).

Mounds: Mounds are made so as to improve on the exploitable volume of the soil for cultivation. The mounds are usually arranged in a straight line or staggered depending on the farm location on the topography and the crop being cultivated. The mounds are usually planted to yam (*Dioscorea sp*.) and cassava (*Manihot esculenta*) in the Northern Region and millet (*Panicum collonum*) or sorghum (*Sorghum bicolor*) in the Upper Regions.

Ridging: Ridging across slope is commonly used to control soil erosion. In critical situations tied-ridging is used. It controls runoff and conserves soil better.

Strategies for effective soil conservation also involve agronomic measures such as shifting cultivation, crop rotation, cover crops, mulching, mixed cropping, strip cropping, agroforestry, revegetation and afforestation, good grazing land management, minimum tillage and contour ridges.

Soil and water conservation research

Integrating conservation technologies that are acceptable to farmers into the Ghanaian farming system is essential for land degradation control in the country. Some of the technologies that have been studied in the Ghanaian environment include mulching, crop rotation, mixed cropping, and vegetative barrier. Others are zero tillage, ridging, minimum tillage and contour bunds. Bonsu (1981), Bonsu and Obeng (1979a), Bonsu and Obeng (1979b) and Quansah and Baffoe-Bonie (1981) gave an insight into some of such research work.

Most research works carried out in the country were geared towards soil fertility with little or no data taken on physical soil conservation, although most of these works impacts positively on the soil physical status. However, a number of research works have been carried out using short-term trials to establish the effectiveness of different systems capability to control soil loss. These involve strip cropping, ridging across slope, zero and minimum tillage, mulching, organic manure, liming, contour vegetation barriers. A list of some of these work and their authors were given by Bonsu et al. (1996).

Research work done in the country so far shows mulching and ridging across slope as an important soil and water conservative measure. This could be live or dry mulch using cover crop or crop residue. Crop residue left on the soil surface is important in preventing crust, increasing organic matter content of the soil, improving its tilth and increasing infiltration (Lal, 1976). The major problem is the availability of material for mulching due to activities of annual bush burning and removal of crop residue to feed livestock. Table 2 shows soil and organic matter loses for ridging across slope and mulching. Mulching and ridging were identified by Bonsu (1981) as good practices compared to groundnut cover, minimum tillage and mixed cropping evaluated using millet as the test crop at Nyankpala in northern Ghana.

Table 2: Soil, water and organic matter (O.M) losses and millet grain yield for different cultivation systems in the Sudan savanna zone of Ghana.

Cultivation system	Runoff (mm)	Soil loss (t ha^{-1})	Millet grain yield (kg ha^{-1})	Runoff O.M %	Eroded sediment O.M %
Ridging across slope with millet-groundnut-Bambara intercrop	6.12	0.69	700	3.0	0.20
Minimum tillage with millet-groundnut-Bambara intercrop	8.37	0.95	1450	5.3	0.80
Rotovating with millet-groundnut rotation	11.43	1.34	1275	1.9	0.50
Ridging across slope with millet-groundnut rotation	7.61	0.87	1090	2.0	0.20
Rotovating + straw mulch with millet-groundnut rotation	7.63	0.86	1090	3.8	0.30
Rotovating with millet sole crop	12.33	1.41	875	3.8	3.10
Control (bare)	18.70	2.34	-	3.8	1.50

Source: Adapted from Bonsu and Obeng (1979a)

In the study of different conservation measures in the Forest-savanna transition zone on a 3% slope, Bonsu and Obeng (1979b) showed that mulching is the most effective way of conserving soil as it results in the least soil loss compared to the other methods such as no-tillage, minimum tillage, ridging across slope and mixed cropping. Also in the Guinea savanna zone on a 2% slope, Bonsu et al. (1996) showed that mulching is comparatively better in terms of soil loss among other methods. In both studies it was observed that repeated application of soil conservation practices resulted in declining soil loss.

Table 3 shows that although cow dung is effective in improving crop yield it does not limit soil loss effectively as compared to the use of straw mulch, which has a long term effect in conserving the soil.

Table 3: Effectiveness of cow dung as influenced by mulching in soil and water conservation at Nyankpala in the Guinea savanna zone.

Treatment	Runoff (mm)	Soil loss (t ha^{-1})	Millet grain yield (kg ha^{-1})
2 t ha^{-1} cow dung	8.16	1.39	0.84
4 t ha^{-1} cow dung	5.26	1.04	1.37
4 t ha^{-1} cow dung + 4 t ha^{-1} straw mulch	2.51	0.08	1.47
5 t ha^{-1} cow dung	4.20	0.91	1.52
5 t ha^{-1} cow dung + 4 t ha^{-1} straw mulch	2.04	0.06	1.59
Control	21.87	5.18	

Source: Bonsu (1985)

In an experiment, using maize (*Zea mays*) and cowpea (*Vigna unguiculata*) as test crops in mulched and unmulched situations, Quansah et al. (1997a) found mulching to significantly reduce runoff and soil loss. Also increasing mulch rate reduced runoff and soil loss. It was observed that cowpea reduced runoff and soil loss better than maize. They obtained the following expressions for the relationship between soil loss and runoff using maize and cowpea:

$$\textit{Soil loss} = 0.051 \; x \; \textit{Runoff} - 0.093 \; (R^2 = 0.89) \qquad \text{For maize}$$

$$\textit{Soil loss} = 0.017 \; x \; \textit{Runoff} - 0.0204 \; (R^2 = 0.78) \qquad \text{For cowpea}$$

The equations indicate that for the same amount of runoff, cowpea limits the soil loss better, indicated by a smaller coefficient for the runoff. With the positive linear relationship between soil loss and runoff, it implies that increasing runoff increases soil loss.

Quansah et al. (1997b) showed that the selective removal of fine soil particles that is high in soil fertility constituents leads to loss of soil fertility. When this is translated into fertilizer in terms of the major nutrients only, one can estimate the cost of nutrient lost. Mulching was shown to result in 2-3 times less loss of the major nutrients (Table 4). With tillage practices, minimizing the number of tillage operations can reduce soil loss as illustrated by Baffoe-Bonie and Quansah (1975).

Table 4: Soil loss, runoff, and the loss of total N, available P, available K, and organic matter (O.M.) on 5% slope on Ferric Acrisol in the Semi-deciduous forest, using maize as the test crop.

Treatment	Soil loss ($t\ ha^{-1}$)	Runoff (mm)	Total N ($t\ ha^{-1}$)	Available P ($t\ ha^{-1}$)	Available K ($t\ ha^{-1}$)	O. M. ($kg\ ha^{-1}$)
Bare plot	2.8	60	8.8	0.019	0.68	166
No mulch	2.2	39	5.2	0.011	0.55	71
2 tha^{-1} mulch	1.4	31	3.5	0.006	0.28	40
4 tha^{-1} mulch	1.6	29	2.8	0.005	0.24	38
6 tha^{-1} mulch	1.0	27	1.5	0.002	0.13	25

Source: Quansah et al. (1997a; 1997b)

Different soil conservation practices gave significantly less soil loss as compare to the bare soil (Table 5). Mulching gave the least runoff and soil loss. Cover crops have been studied for controlling weed and as mulch for improving soil organic matter. In the past Mucuna (*Mucuna pruriens*) (Boateng, 1997) and other cover and leguminous crops have been studied (Fosu et al., 2001; Agyare et al., 2002).

Vertisols are known to be inherently fertile; however the need for timely cultivation at the appropriate moisture regime has in the past led to low cultivation of vertisols. To address this problem Ahenkorah and Oteng (1996) evaluated different landforms to identify a suitable technology for intensive cultivation of vertisols using maize as the test crop. As presented in Table 6 the cambered bed is the best type of bed among the flat bed, ridges and Ethiopian bed at both on-station and on-farm level.

Table 5. Three year (1974-1976) mean soil loss and runoff for different conservation practices in the Forest savanna transition zone of Ghana.

Treatment	Soil loss	Runoff (% rain)
Control (bare)	200.03^{b}	43.93^{c}
Minimum tillage	3.24^{a}	8.80^{ab}
Mixed cropping	18.76^{a}	13.50^{b}
Mulching	0.44^{a}	2.13^{a}
No tillage	3.84^{a}	6.90^{ab}
Ridging across slope	3.60^{a}	7.43^{ab}
SED (p)	35.34 (0.001)	4.32 (0.000)

Mean values with the same letters in a given column are not significantly different at $p < 0.05$

Source: Bonsu and Obeng (1979b)

Table 6: Maize grain yield (t ha^{-1}) for three levels of fertilizer application rate effect on four landforms on-station and two landforms on-farm on a vertisol in the Coastal savanna

Landform	Percentage of recommended fertilizer rate at on-station			On-farm
	0	50	100	
Flat bed	0.700^{b}	1.387^{c}	2.422^{b}	0.912^{b}
Ridges	0.842^{ab}	1.867^{bc}	2.960^{ab}	
Ethiopian bed	1.149^{a}	2.057^{b}	3.114^{a}	
Cambered bed	1.213^{a}	2.767^{a}	3.458^{a}	1.726^{a}
LSD		0.3076 ($p<0.5$)		P=0.032 SED=0.253

Mean values with the same letters in a given column are not significantly different at $p < 0.05$

Source: Ahenkorah and Oteng (1996)

Most research on soil and water conservation has been done by individuals and separate projects without drawing much synergy between them. There is therefore need for effective coordinated research program that integrates several types of soil and water technologies, so as to develop good conservation practices and procedures that are designed for specific sites.

Extension activities

A coordinated approach towards solving the problem of land degradation is very important. The existing research, extension and farmer linkage is a healthy one and must be encouraged. Increasing the number of extension workers will increase the contact hours extension staff have with farmers. However, paramount to this is training and upgrading of extension staff knowledge on soil and water conservation.

In the field of extension, the Ministry of Food and Agriculture (MoFA) has prepared manuals on vegetative barriers, contour bunds, composting and Mucuna use for soil fertility improvement to help extension staff to train farmers on the aforementioned issues. These have to be built on to cover other areas of soil and water conservation. The two main departments of MoFA that deals directly with soil and water conservation issues are the Agricultural Engineering Services Division (AESD) and land and Water Management Unit (LWMU) of the Crop Services Division (CSD). The AESD focuses on tillage and lowland earth bund for lowland rice cultivation whiles the LWMU focuses on cultural practices. Non-Governmental Organizations (NGO) such as TRAX have also been working with farmers in the Northern and Upper East Regions on conservation practices such as stone and earth bunds, and crop residue management and cover cropping.

Constraints to soil and water conservation in Ghana

The question asked most often is, why is soil conservation not widely applied and so much land is wasted in spite of millions of people suffering from hunger? Soil and water conservation needs are much wider than just application of conservation technologies; it requires good policies by which soil conservation becomes an integral part of a general land use that forms part of socio-economic environment which is conducive to the maintenance and improvement of the soil capital. Issues of soil and water conservation have to be address at the catchment or watershed level where all efforts reinforce and complement each other. It requires community participation, most especially in developing country such as Ghana where farm holdings are relatively small.

There are some socio-economic factors that militate against effective and efficient adoption of soil and water management practices. These include land tenure system, gender discrimination, poverty, lack of alternative economic activity, lack of farmer involvement in planning, and introduction to technologies that are alien to the existing farming system (Bonsu et al. 1996). A key constraint to soil conservation is the issue of landownership, with most farmers having no permanent title to a piece of land. Pressure on land has increased due to increasing population and therefore creation or provision of alternatives to working on land is very crucial. Land fragmentation as a consequence of progressive sub-division of land holdings makes conservation practices not attractive to implement.

The human desire to always stay with the "status quo" and not move from their accustomed practices and environment means it takes a bit more to convince farmers to participate in conservation practices. This is in addition to the fact that farming in Ghana is a way of surviving rather than a business and therefore farmers find it more difficult to take risk. The lack of political will or power to translate words into programs as most funds for conservation works are most often than not diverted for infrastructural development that are eye catching. Also the lack of enforcement on laws on national forest reserves encourages illegal encroachment. Community enforcement of conservation practices through education is always better than legislation on land use (Hudson, 1981). In summary the major constraints to good soil management practices in Ghana hinges on poverty and land tenure system. Other factors include lack of awareness of the benefits of good soil management and the long-term repercussion of soil degradation, social customs that abuse the use of land, and lack of capital to enable farmers to invest in their land.

Future perspective

Analysis of land use plans in the context of farmers' natural environment and socio-economic circumstances is essential to achieving the soil conservation goal. Soil and water conservation must be tackled from two fronts i.e. technological and regulatory. The technological component must adopt the use of an integrated approach where soil and water conservationists and socio-economists look at conservation holistically.

Research must continue to help to identify alternatives and best bet conservation technologies for the different ecological zones, soil type, and landscape condition (e.g. slope and elevation). The use of remote sensing data and GIS tools must be considered as it will enhance broader understanding and application of solutions to land degradation problems. The issue of technology transfer must be considered through capacity building and logistic provision. The use of good and appropriate soil and water conservation practices of cereal-legume crop rotation and intercrop, tie-ridging, contour ridging, mulching, cover crops, vegetative barrier such as vertiver grass, contour earth and stone bunds, and the use of water harvesting techniques need to be encouraged. Studies on the adoption rate of such technologies must be carried to understand how farmers accept these innovations.

Considering that soil and water conservation takes considerable time to show gains, the most appropriate option is to take land as a national asset, so that its development, use or exploitation are taken into national planning programs. In terms of regulation, the focus must be to establish a landuse planning and regulatory body. ie A national Agricultural Landuse Planning Department as a parallel department to that of Town and Country Planning to oversee the effective planning and use of agricultural land. This department should adopt the use of self (e.g. professional bodies and community groups) and social (e.g. persuasion, information and education) regulatory mechanisms. Soil conservation planning should take place from the farmer to the national and if possible sub-regional level.

Conclusion

We are not winning the context of man against soil degradation. There are still knowledge gaps that need to be filled and constraints pertaining to political, social and economic issues yet to be addressed. The current trend of widespread land degradation has an impending danger of derailing the agricultural development of the country. This calls for a greater awareness creation that cuts across all levels, from the farmer to the policy maker. A great amount of work has been done on soil and water conservation in Ghana. These include research and extension work in the field of runoff control using ridges, earth and stone bunds, mulching, cow dung and appropriate tillage practices. However, these efforts are carried out in bits and pieces across the country and needs coordination. Mulching is identified as the most effective soil and water conservation measure among many others evaluated in the country. In brief, integrating conservation practices into existing farming systems is a pre-requisite to sound soil management.

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Chapter 9

Integrated Soil, Water and Nutrient Management for Sustainable Irrigated Rice Systems in Burkina Faso

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Abstract

Analysis of Kou Valley and Bagré irrigated rice cropping systems in Burkina Faso (West Africa) found agronomic constraints similar to the situation in other schemes of the region. Yield gaps between average farmers' yield and best farmers' yield were high and indicated considerable scope for yield and profit increases in both dry and wet seasons. The importance of nutrient management, especially for nitrogen (N) for yields was demonstrated. N uptake by the crop was a major yield-limiting factor. Increasing the amount of N in the crop equated to increased yields. Economic analysis presented linked N application rates, N recovery rates, and yields to cost of fertilizers, net returns, and financial risks in fertilizer use. Farmers with high nitrogen-use efficiency also had high net returns to fertilizer use. Analysis of the two irrigated rice cropping systems strongly indicated that higher input use efficiency, higher yields and higher financial returns can be achieved without major new additional investments or development of new technology. The most promising ways to achieve higher productivity and input use efficiency are: (i) to avoid seeding after 15 august, (ii) to improve timing and quality of crop management practices, and (iii) to improve existing fertilizer recommendations. The rice phenology model "RIce DEVelopment" (RIDEV) and other tools based on existing knowledge can be used to alleviate these knowledge gaps. Additionally, the institutional environment in which farmers are currently operating needs to be improved. The Integrated Rice Management (IRM) strategy must be developed in irrigated rice schemes to increase rice production and productivity, through a site-specific nutrient management (SSNM) approach.

Keywords: *Integrated rice management, Nitrogen-use efficiency, Productivity, Site-specific nutrient management, Burkina Faso.*

Résumé

L'analyse des rizieres de la valee irriguee de Kou et de Bagre au Burkina Faso (Afrique de l'Ouest) montre des contraintes agronomiques similaires a d'autres situations de la region. Les gaps entre les rendements moyens des paysans et les meilleures rendements obtenus sont tres eleves indiquant une grande possibilite de rendements et des profits autant en saison seche qu'en saison humide. L'importance de l'utilisation d'amendements mineraux, speciallement l'azote a ete demontre d'autant plus que cet element est un facteur limitative de la production. Augmenter les doses d'azote est synonyme d'augmentation de rendement. L'analyse economique presente un lien entre les doses appliqués d'azote, l'azote recouvre et les rendements d'une part; le cout des engrais, les gains nets, et les risques d'investissement en engrais. Les paysans ayant une efficacite d'utilisation de l'azote elevee recoivent en retour des gains plus eleves lies a l'utilisation des engrais. L'analyse des deux rizieres montrent clairement qu'on peut obtenir des bons rendements, une bonne efficacite d'utilisation d'intrants et des gains financiers eleves sans gands investissements ni nouvelles technologies. Pour atteindre un niveau de productivite eleve et une efficacite d'utilisation d'intrants, il faut: (i) eviter de semer après le 15 aout, (ii) ameliorer le calendrier et la qualite des pratiques culturales, (iii) ameliorer les recommendations existantes en matiere d'utilisation d'engrais. Le model de phenologie du riz et d'autres outils bases sur les connaissances traditionnelles peuvent etre utilisees pour combler les gaps entre connaissances diverses. En plus, l'environnement institutional dans lequel les paysans operent actuellement a besoin d'etre ameliore. La strategie de gestion integree du riz(GIR) doit etre developpee dans les rizieres pour accroitre la production et la productivite a travers une approche de gestion des nutriments sur des sites specifiques(GNSS).

Mots cles: *Gestion integree du riz, efficacite de l'utilization de l'azote, Productivite, Gestion des nutriments sur site specifique, Burkina Faso*

Introduction

Rice consumption in Burkina Faso is growing at 3% per year, especially due to increased demand in urban centres (Randolph, 1997). Although the total surface area grown to irrigated rice is relatively small (only 20% of total rice area), its contribution to marketed national production is substantial (about 50%) and still growing (WARDA, 1996). Annual paddy production during recent years (1996 to 2000) was about 100 Mt yr^{-1}, with imports ranging from 105 to 240 Mt yr^{-1} (FAO, 2002).

Although the potential of irrigated rice (*Oryza sativa* L.) in the Sahel is as high as 8 to 12 t ha^{-1} (Dingkuhn and Sow, 1997) and best farmers regularly achieve paddy yields of 7 to 9 t ha^{-1}, various authors confirmed average yields of 3.0 to 5.5 t ha^{-1} in the Sahelian irrigated systems (Matlon et al., 1996; Wopereis et al., 1999; 2001; Haefele, 2001; Haefele et al., 2000; 2001; 2002). Average yields of irrigated rice in Burkina Faso were estimated at 4.0 to 4.5 t ha^{-1} (Wopereis et al., 1999; Segda, 2001). These medium to low average yields are far below the level anticipated by authorities and irrigation scheme planners, and threaten the economic sustainability of irrigated rice in the country (6 – 7 t ha^{-1}). Low yields combined with high input prices cause low profit margins, which subsequently reduce savings for maintenance of infrastructure and machines and the return of credit debts to the bank. Due to the direct competition of local rice producers with cheap Asian rice imports, price increases on the local markets cannot be expected in the near future. Therefore, the economic viability of the costly irrigated rice schemes in the Sahel can be questioned (Bélières et al., 1997). However, it is estimates that local rice would become competitive facing the imported rice (Raveau, 1998) provided that paddy yields continue to progress to maintain themselves between 5.5 and 8.0 t ha^{-1}, and that the paths are organized. The present stake is therefore to valorise the existing infrastructures economically while sustaining the development of the social capital (Nepveu et Villemarceau and *al*., 2001). The contribution of irrigated rice in the fight against poverty and the food insecurity necessarily passes by an improvement of the productivity of rice fields while reducing the gaps between the potential and actual paddy yields

This background demonstrates the urgent need to improve productivity while maintaining input costs at or close to the present level. Considerable increases of investments in inputs are not likelye to the limited financial means of small-scale farmers. But crop management adjusted to the local environment can contribute to improved productivity at current input levels.

Suboptimal fertility management, late transplanting, suboptimal weed management, spikelet sterility, and late harvesting have been identified as widespread agronomic constraints and have an important impact on rice productivity, resource-use efficiency, and return to investments (e.g., Wopereis et al., 1999; Haefele et al., 2000, 2001; Segda et al., 2004) Evaluation of improved soil fertility and weed management practices in collaboration with farmers in Mauritania and Senegal confirmed these findings, and substantial yield increases were achieved (Haefele et al., 2000). In a similar but larger study, Kebbeh and Miézan (2003) demonstrated that considerable productivity gains with lower production risk were possible without increasing costs, through sequential adoption of integrated crop management options.

This review paper focuses on two major points: (i) the characterization of irrigated rice cropping system based in socio economic surveys and (ii) the development of site-specific nutrient management recommendations.

The first point is based on the works of Wopereis et al. (1999), Donovan et al. (1999) and Segda et al. (2004) who conducted agro-economic characterization studies in two of the most important rice irrigated schemes in western and eastern Burkina Faso (Kou Valley and Bagré plain), where development of irrigation schemes are ongoing. The following results on general characteristics of irrigated schemes, soil analysis, weather induced sterility, soil fertility and fertilizer management, crop management, yields and yield gap estimation, indigenous nitrogen supply and N-use efficiency, economic analysis were briefly presented.

The second point focuses in the necessary to identify site-specific constraints and opportunities for irrigated rice cropping in main irrigated rice schemes, by combining participatory on-farm research, detailed agro-economic surveys and crop modelling. Such an integrated approach is vital, taking farmers' socio-economic as well as bio-physical environment into account. These results have then been used to propose alternative crop management practices that may increase input-use efficiency and productivity.

Table 1. General characteristics of irrigation schemes and specific characteristics of the surveys conducted in Kou Valley (Wopereis et al, 1999) and Bagré plain (Segda et al, 2004)

Site	Kou Valley		Bagré	
Location	11°11’ N 4°18’W		11°30’ N, 0°25’ W	
Surface area (ha)	1260		1600	
Water source	Diversion of Kou river (gravity flow)		Bagré dam (gravity flow)	
Minimum air temperature (°C)	15 to 17 in December and January		15 to 17 in December and January	
Maximum air temperature	35 to 38 in March and April		34.9 (mean) in March and April	
Rainfall (mm year^{-1})	1200		900 mm	
Introduction of irrigated rice cropping	1970		1980 (Little Bagré) and 1997 (Great Bagré)	
Land preparation	Animal power		Animal power or Tractor-driven disk plough	
Harvesting method	Manually		Manually	
Threshing method	Mechanically and manually		Mechanically and manually	
Recommended N fertilization for the wet season	100 kg urea ha^{-1} in 2 splits, 35% at start of tillering and 65% at PI		100 kg urea ha^{-1} in 2 splits, 35% at start of tillering and 65% at PI	
Recommended N fertilization for the dry season	150 kg urea ha^{-1} in 2 splits, 50% at start of tillering and 50% at PI		150 kg urea ha^{-1} in 2 splits, 50% at start of tillering and 50% at PI	
Recommended P fertilization for both wet and dry seasons	300 kg CF ha^{-1} shortly after transplanting		300 kg CF ha^{-1} shortly after transplanting	
Recommended K fertilization for both wet and dry seasons	In CF (see above)		In CF (see above)	
Total N-P-K recommendation for the wet season (kg ha^{-1})	88-30-35		88-30-35	
Total N-P-K recommendation for the dry season (kg ha^{-1})	111-30-35		111-30-35	
Principal cultivar	ITA123		TOX 728-1	
Establishment method	Transplanting		Direct-seeding Transplanting	
Season	WS 1995 and DS 1996		DS 1999 and WS 2000	
Soil	Clay loam	Sandy clay loam	Clay loam	Sandy loam
Cropping system	Double-cropped	Double-cropped	Double-cropped	Double-cropped
Number of farmers	20	20	11	9

WS: wet season; DS: dry season; DAT: days after transplanting; PI: panicle initiation; CF: cotton fertilizer, containing 14% N, 10% P, 12% K (Kou valley) or containing 12% N, 11% P, 10% K (Bagré plain)

Material and Methods

Characterization of irrigated rice cropping systems in Burkina Faso

Socio-economic surveys: Field surveys were conducted (i) in the Kou valley during the 1995 wet season (WS) and the 1996 dry season (DS) and (ii) in the Bagré perimeter during the 1999 DS and the 2000 WS (for details see Wopereis et al, 1999 and Segda et al., 2004). The survey was successfully conducted with 16 farmers in the DS and with 12 farmers in the WS (in Bagré) and 20 farmers each season for Kou valley. Farmer participation was on a voluntary basis and not randomised. Agronomic practices were monitored with assistance of extension officers. All crop management practices as well as all expenditures were recorded in weekly interviews with farmers during the growing season. Participating farmers were requested to manage their rice crop in the selected field according to their usual practice (T_F), i.e. with their own choice of fertilizer applications and their usual crop management practice. No recommendations were given to farmers prior to the start of the surveys. In each field, a sub-plot of 10 m x 10 m was established, separated from the main field by bunds. Sub-plots were managed using the same crop management practices as in T_F, but no fertilizer was applied (T_0).

The following issues were addressed in these interviews: surface area of all fields, use of pre-irrigation, use of basal fertilizer, timing of crop management interventions, such as sowing, fertilizer application, herbicide application, drainage and harvesting, type of fertilizer and/or herbicide applied, application rates, mode of application, date of drainage and harvest, costs of fertilizer and herbicide treatments, costs to transport fertilizer and paddy price. Farmers' perceptions of major constraints to rice cropping were determined at the onset of the 1997 WS, by asking them to rank their three major constraints in decreasing order of importance. Constraints were given a weighing factor of 1 (most important constraint), 0.67 (second important constraint) and 0.34 (third constraint). Average weights were then determined for each constraint mentioned by farmers.

The model RIDEV, developed and validated for Sahel and Sudan Savanna regions in West Africa (Dingkuhn, 1997), was used to evaluate farmers' crop management practices. The model estimates crop growth duration and spikelet sterility due to cold or heat stress. Inputs for the model are daily minimum and maximum air temperature, photothermal constants of the cultivar used, sowing date, and establishment method. Outputs are predictions of growth duration, spikelet sterility due to heat or cold stress, and phenological stages of the rice crop, i.e. start of tillering, panicle initiation, heading, flowering and maturity. This can be used to estimate optimal sowing date, optimal timing of N fertilizer applications (either only split applications at the start of tillering and panicle initiation, or three splits adding a third application at heading), timing of the last drainage before harvest (two weeks before maturity), and timing of harvest.

Indicators of input use efficiency: Indigenous N supply (INS) was estimated from plant N uptake in T_0 plots (Dobermann and White, 1999; Wopereis et al., 1999).

Partial-factor productivity of applied N (PFPN) is the amount of grain produced per unit nitrogen applied and is calculated based on total grain yield at maturity in a treatment where N was applied (GY_{+N} in kg ha^{-1}) and the amount of fertilizer N applied (FN in kg ha^{-1}) according to $PFPN = GY_{+N}/FN$ (Cassman et al., 1996). Recovery fraction of applied N (RFN) is calculated from total aboveground nitrogen uptake at physiological maturity in plots that received applied N (UN_{+N}) at the rate FN (kg ha^{-1}), and total aboveground N uptake in plots without N application (UN_{0N}) according to the equation: $RFN = (UN_{+N} - UN_{0N})/FN$. Internal efficiency of nitrogen (IEN) is defined as grain yield per kg nitrogen taken up and is calculated as IEN = GY/UN.

Soil and plants analysis: Five soil cores (0.0 to 0.2 m depth) were collected from each T_0 plot before the onset of the growing season and composited into one sample per plot. Soil analysis included pH H_2O (1:2,5 extract), electrical conductivity of the 1:5 soil-extract (EC), P-Bray1, and exchangeable bases (extraction with ammonium chloride) according to van Reeuwijk (1992). The Walkley-Black method (Nelson and Sommers, 1982) was used to determine total C, and total N was determined according to Bremner (1996).

Paddy yields and grain moisture content were measured from a 6-m^2 area harvested in each T_0 and T_F plot. Grain yields were corrected to 14% moisture content (or to 3% moisture content for N uptake calculations). Harvest index was determined from oven-dry (70°C resulting in 3% moisture content) straw and grain weight of a 12-hill sub-sample or a 0.5 m^2 area in case of direct seeding. Nitrogen concentrations in grain and straw samples were determined using the standard Micro-Kjeldahl procedure (Bremner, 1996).

Developing site-specific nutrient management recommendations. The case of Bagré irrigation scheme

To improve existing crop and nutrient management recommendations and practices, an integrated approach is vital, taking the farmers' socio-economic as well as bio-physical environment into account. Nutrient management for rice should focus on developing fertilizer recommendations for spatial domains with relatively uniform agro-ecological characteristics, cropping practices, and socio-economic conditions (Dobermann et al., 2002; 2003a and b).

To reach that goal with agronomic trials is rather costly and time consuming, and simulation tools are increasingly used as a complement (Smaling and Janssen, 1993). This approach combines field data with simulation tools in a flexible framework. It helps the user to diagnose limiting factors as well as to develop soil fertility management strategies as a function of his or her goals, e.g. profit maximisation, yield maximisation or minimising risk, given biophysical and socio-economic settings.

The second part of this study intended to: (i) estimate climatic risk in Bagré for the two rice growing seasons and for different crop establishment modes and dates, (ii) develop agro-economically sound fertilizer recommendations for a range of target yields using the framework presented by Haefele et al. (2003b); and (iii) evaluate such model-based alternative recommendations in farmers' fields.

Improved fertilizer recommendation: Fertilizer recommendations in Burkina Faso have not changed since the introduction of irrigated rice since 1960's and are presently uniform over large areas and cut across diverse climatic and edaphic environments (Nebié, 1995; Wopereis et al., 1999). Given the magnitude of field-to-field variation within small areas with similar soil type, this approach results in inefficient use of nutrients and limits efforts to increase average farm yields because of nutrient deficiencies, excesses, and imbalances (Cassman et al., 1998). Nutrient management for rice should focus on developing fertilizer recommendations for spatial domains with relatively uniform agro ecological characteristics, cropping practices, and socio-economic conditions (Dobermann et al., 2003b). Because mineral fertilizers are increasingly expensive, it is evident that they must be used efficiently. Substantial improvements in nutrient use efficiency and economic performance require a site-specific nutrient management (SSNM) approach. Site-specific nutrient management (SSNM) as the dynamic, field-specific management of nutrients in a particular cropping season to optimise the supply and demand of nutrients according to their differences in cycling through soil-plant systems (Dobermann and White, 1999). The major components of a field-specific, knowledge-based strategy are quantification of crop nutrient requirements based on nutrient interactions and economic yield target, measurement of potential N, P, and K supply; and monitoring of plant N status to optimise N nutrition. Site-specific nutrient management (SSNM) concepts have been developed in recent years as alternatives to the use of blanket fertilizer recommendations for large areas. These new approaches aim to achieve efficient fertilizer use and balanced fertilization. They offer profit increases to farmers, higher yields per unit of applied fertilizer and protection of the environment by preventing excessive use of fertilizers.

Framework development: Two simulation tools were used to develop AFR. The rice phenology model RIDEV (Dingkuhn, 1997) assists in the optimal timing of crop management interventions, and a modified version of QUEFTS (Janssen et al., 1990) called FERRIZ is used to calculate N, P, and K doses for specific target yields. The framework and the simulation tool FERRIZ are described in detail by Haefele et al. (2003b). A short description of the models is given below.

RIDEV simulations of crop duration and sterility were conducted for the cultivar Sahel 108 (IR 13240-108-2-2-3), which is similar to short duration cultivar FKR 19 (TOX 728-1). Simulations were conducted at 7-days intervals over a period of 10 years. The simulations used the dominant crop establishment techniques in each season, which is direct seeding in the dry season and transplanting in the wet season (Segda et al., 2004). Best timing of crop management interventions as a function of sowing date and risks of yield loss due to temperature extremes (low temperatures in WS and high temperatures in DS) were determined.

FERRIZ was used to calculate fertilizer doses for target yields ranging from 6.0 to 8.0 tha^{-1} in 0.5 t ha^{-1} intervals in the dry season (Y_{pot} = 9.0 tha^{-1}) and from 5.0 to 7.0 t ha^{-1} in the wet season (Y_{pot} = 8.0 t ha^{-1}). Total N, P and K uptake at harvest were estimated as well. Fertilizer costs were based on average prices for the 2003 and 2004 wet and dry seasons of the most commonly applied fertilizers in the Bagré plain, i.e. urea (0.46 US $ A kg^{-1}, containing 46% N) and "cotton fertilizer" (0.48 US $ kg^{-1}, containing 12% N, 10.5% P and 10% K). The paddy price depends on the milling recovery rate, and the producers of Bagré achieved an average price of 0.19 US $ per kg paddy over the four growing seasons in 2003 and 2004. The average exchange rate of the West African currency FCFA to the US dollar in the period 1 January 2003 – 31 December 2004 was US$ 1.00 = 554 FCFA.

The outcome of the FERRIZ simulations allowed the development of alternative fertilizer recommendations (AFR). FERRIZ was then used to estimate yields and yield differences that can be expected from existing fertilizer recommendations (EFR) and from the alternative fertilizer recommendations (AFR) in both wet and dry seasons.

Validation trials: Three fertilizer treatments were tested with 7 farmers in the 2003 DS (February sowing), 13 farmers in the 2003 WS (July sowing), 17 farmers in the 2004 DS (February sowing) and 12 farmers in the 2004WS (July sowing):

(i) farmers' practice in terms of fertilizer use (FP)

(ii) EFR, with urea applied in two splits; i.e. 35% at 15 days after transplanting (DAT) and 65% at panicle initiation (PI)

- in the dry season: 105 kg N, 31 kg P, 30 kg K ha^{-1} as 300 kg "cotton fertilizer" ($N/P_2O_5/K_2O$ 12/24/12) and 150 kg urea ha^{-1}
- in the wet season: 82 kg N, 31 kg P, 30 kg K ha^{-1} as 300 kg "cotton fertilizer" and 100 kg urea ha^{-1}

(iii) AFR, with urea applied in three splits: 3/8 at early tillering; 3/8 at panicle initiation and 2/8 at booting; timing of fertilizer application guided by RIDEV. Although AFR were developed for both WS and DS, farmers only adopted the "low" AFR developed for the WS, i.e.: 116 kg N, 21 kg P and 20 kg K, as 200 kg "cotton fertilizer" and 200 kg urea ha^{-1}

Farmers typically used short duration rice cultivar TOX 728-1, or similar short-stature high yielding cultivars. In each rice field (typically about 1 ha in size), three subplots of 10 m x 10 m were installed to evaluate AFR, EFR and FP. For AFR and EFR, all management practices were left to the farmer, except fertilizer applications. For FP, all management practices, including fertilization were left to the farmer. At maturity, rice yields were obtained from a $6m^2$ surface area in the centre of each subplot and yields were corrected for 14% moisture. Profit margins from fertilizer use were determined for each treatment using prices for each season.

Financial calculations were made on a per crop basis following Dobermann et al. (2002) using US $ as standard currency:

$$\text{TFC} = P_N F_N + P_P F_P + P_K F_K$$

$$\text{GRF} = P_R Y_R - \text{TFC}$$

where TFC is the total fertilizer cost, GRF the gross return above fertilizer cost, Y_R the rice yield, P_R the price for rice, P_N the price of N fertilizer, P_P the price of P fertilizer, and P_K the price of K fertilizer, F_N the quantity of N fertilizer applied, F_P the quantity of P fertilizer applied and F_K the quantity of K fertilizer applied.

The incremental profitability of AFR (dGRF) was determined as the difference in gross returns above fertilizer costs between AFR and FP and between AFR and EFR:

$$\text{dGRF} = \text{GRF}_{AFR} - \text{GR}_{FP} \quad \text{or}$$

$$\text{dGRF} = \text{GRF}_{AFR} - \text{GR}_{EFR}$$

Statistical Analysis: Statistical analysis followed methods described by Gomez and Gomez (1983) using STATISTICA software (StatSoft). Treatment means were compared with the Duncan multiple range test. The *P* level used for significance in the analysis of variance was always 0.05 and in the Duncan multiple range was set to 0.05.

Results and Discussions

Characterization of irrigated rice cropping systems in Burkina Faso: General characteristics of irrigation schemes are presented in Table 1. Field surveys were conducted in the Kou Valley during the 1995 wet season (WS) and the 1996 dry season (DS) and in the Bagré perimeter during the 1999 DS and the 2000 WS (for details see Wopereis et al, 1999 and Segda et al., 2004). Surveys were successfully conducted with 17 farmers in the DS and with 12 farmers in the WS (in Bagré) and 20 farmers in each season for Kou Valley.

In both sites, main crop is irrigated rice, which is cultivated in the wet season (WS; sowing from July to August) and the hot dry season (DS; sowing from January to February). Almost 100% of the irrigated area is cropped twice a year. Direct seeding (only in Bagré) and transplanting are both practiced. Land is prepared using animal traction, and manual harvest and threshing are dominating. Dominating cultivars are FKR19 (TOX 728-1) and FKR14 (4418). Apart from irrigated rice, most farmers grow rainfed maize, millet, or sorghum in the surroundings of the schemes during the wet season and some farmers grow vegetables during the dry season. Most farmers also own some cattle.

Soil analysis: General soil characteristics like soil reaction (pH) and soil salinity (EC) were within favourable ranges for rice growth, and high Ca and Mg saturation of the exchange complex as well as low Na saturation indicated considerable buffer capacities with regards to both parameters (Table 2). Most fields sampled showed low values of total soil N and exchangeable K. Observed values of soil parameters correspond well with observations of the national soil survey agency (Bunasols, 1994). Soils in Kou Valley have predominantly 1:1 layer clay fractions with dominating 2:1 minerals, mainly the smectite (Nebié, 1995). Values of extractable soil-P (Bray1 test or P Olsen test) were high for Kou Valley due to large amount of compound fertilizer applied since 1970. Haefele et al. (2001) indicated that in the Senegal River Valley P availability became a limiting factor for rice crops at P-Bray1 values below 4 mg kg^{-1}. Topsoils in the scheme were characterized by medium to low soil organic matter content, total cation exchange capacity and total exchangeable bases. Increased use of organic materials should be encouraged to maintain soil fertility and to supplement mineral fertilizers. Segda et al. (2001) showed in the Kou Valley (Burkina Faso) that continuous use of organic amendments (farmyard manure, compost, rice straw) improved rice production and the efficiency of mineral fertilizers. Most promising in this environment seems the promotion of a better use and higher rate of return of rice crop residues (straw and husks) to maintain the indigenous soil fertility. No relation could be detected between topsoil parameters measured and T0 yield or plant N uptake (data not show), confirming reports by Dobermann et al. (2003a). In irrigated rice, the cumulative effect of management-depending factors (e.g., number of seasons per year, duration of irrigation, organic residue management, soil aeration) seems to affect indigenous soil fertility stronger than chemical or physical soil parameters (see Dobermann et al., 2003a).

Table 2: Average topsoil (0 – 0.2 m) characteristics for the two dominating soil texture groups of participating farmers' fields in the dry season 1999 at Nimatoulaye, Burkina Faso.

		Kou valley		**Bagré**	
Soil characteristics		Mean	SD	Mean	SD
pH_{H_20} (1:2.5 soil extract)		5.4	0.3	6.6	0.53
EC (1:5 soil extract)	(mS cm^{-1})	0.03	0.01	0.05	0.03
N total	(%)	0.09	0.05	0.04	0.01
Total organic C	(%)	0.87	0.38	0.82	0.4
C/N ratio		9.9	3.3	20.5	2,3
P-Olsen	(mg kg^{-1} soil)	14.3	4.6	6.1	2.9
P-Bray1	(mg kg^{-1} soil)	12.6	5.6	5.6	2.9
Ca exchangeable	($cmol_c$ kg^{-1})	3.8	1.2	4.03	2.17
Mg exchangeable	($cmol_c$ kg^{-1})	1.2	0.4	1.78	1.17
Na exchangeable	($cmol_c$ kg^{-1})	0.3	0.1	0.22	0.21
K exchangeable	($cmol_c$ kg^{-1})	0.2	0.1	0.18	0.10
Total exchangeable bases	($cmol_c$ kg^{-1})	5.5	1.4	6.1	2.7
CEC	($cmol_c$ kg^{-1})	5.8	1.6	7.9	1.8

SD: standard deviation

Adapted from Wopereis et al. (1999) for Kou Valley and Segda et al. (2004) for Bagré

Soil fertility and fertilizer management: Farmers in Kou Valley and Bagré applied mineral fertilizers, i.e., compound "cotton fertilizer" (CF), and urea in two splits. In both wet and dry seasons, variability in application date was high as variability in the amount ofrtilizer applied. Existing fertilizer recommendations are 300 kg ha^{-1} "cotton fertilizer" (elemental NPK 14:10:12 for Kou valley and 12:10:10 for Bagré) applied basal or shortly after transplanting and 100 kg ha^{-1} urea (46:0:0) in the WS or 150 kg ha^{-1} urea in the DS. Recommended total NPK dose for Kou valley therefore is 88:30: 35 kg ha^{-1} and 111:30:35 kg ha^{-1} in the WS and DS respectively and 82:31:30 kg ha^{-1} and 105:31:30 in Bagré. Urea is recommended to be top-dressed in two equal splits at early tillering and panicle initiation.

Some farmers applied relatively large amounts (69 to 72 P_2O_5 per season) due to the compound nature of the CF, despite high levels of plant-available P in the soil in Kou Valley (Nebié, 1995) and Bagré (Segda et al., 2004). The compound nature of the NPK fertilizers used by the majority of farmers in the two surveys constitutes, however, a major obstacle for improvement of soil fertility management. Alternative cheaper sources for P (such as Burkina phosphate in Burkina Faso) and K may be available and should be evaluated.

Crop management: The analysis of farmer's crop management revealed considerable differences between actual and optimal timing (according to RIDEV) of crop management interventions such as transplanting, fertilizer application, weeding and harvesting (Figure 1). Few or no problems with weeds were reported both in Kou Valley and Bagré. Farmers were able to control weed growth mechanically, by weeding once or twice during the season, by hand or with a rotating hoe (only in Kou Valley). Most farmers conducted two weedings each season. Preferred weed control method was manual weeding and only in the wet season 5 out of 12 farmers used herbicides (Ronstar, 120 g ai l^{-1}). Quantities applied (1 l ha^{-1}) were far below the recommended dose of 4 l ha^{-1}. Farmers harvested manually, on average 128 days after sowing (DAS) in the wet season (between 110 and 145 DAS), and 117 DAS in the dry season (between 103 and 132 DAS). RIDEV simulations for TOX 728-1 recommend harvest at about 124 DAS (133 days after transplanting "DAT") and 109 DAS (118 DAT) for sowing dates in July and February respectively. The simulation results were confirmed by the low yields of farmers with late sowing date in the WS (Segda et al., 2004). Cold sterility due to late sowing date might be the single most important reason for the low economic return of many farmers during the WS. To improve farmers' respect of the cropping calendar, they should be informed about the consequences of delayed crop establishment in the WS in order to improve their collective and individual crop management planning.

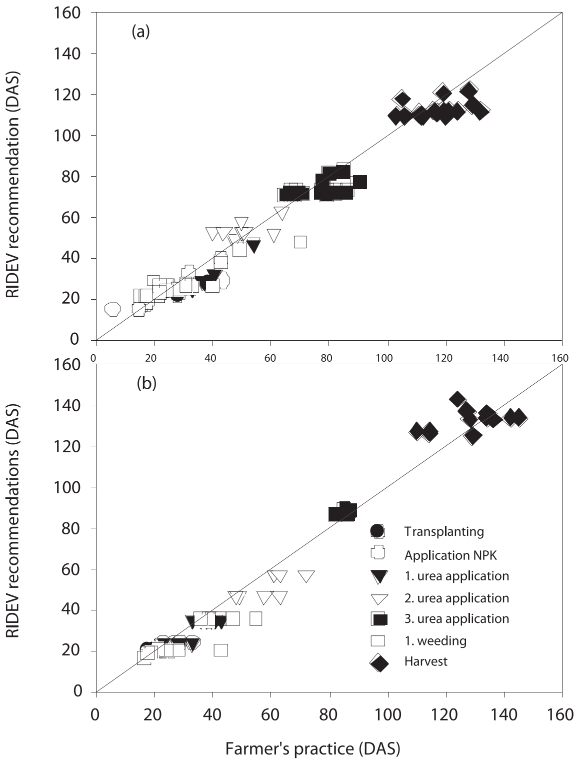

Figure 1. *Actual timing of farmers' practice compared to simulate optimal timing of crop management interventions according to RIDEV. Results are separated for the 1999 dry season (***a***) and the 2000 wet season (***b***) in days after sowing (DAS). Optimal timing was derived using the RIDEV simulation tool as described in the text, Bagré, Burkina Faso.*

Weather induced sterility: RIDEV (Dingkuhn, 1997) simulations indicated that especially wet season yields can be strongly influenced by temperature induced yield losses depending on the sowing date (Figure 2). Sowing after 15 August increased the risk of cold sterility due to low daily minimum temperatures in November, i.e. during the reproductive growth stages.

To avoid problems with spikelet sterility in the wet season, farmers need to transplant their dry-season crop in January, or latest February, to have ample time (at least 2 months) to prepare for the wet season. Most farmers indeed transplanted in February. All farmers in Kou Valley used short-duration cultivar ITA123. There was great diversity in transplanting date and seedling age in both wet and dry seasons Research recommended seedling age at transplanting is 20 days during the wet season and 30 days during the dry season when growth is slow due to cold in December and January. In Kou Valley, comparison with data on minimum air temperature from the Bobo Dioulasso meteorological station revealed that yield losses due to spikelet sterility could be expected if transplanting occurs in September (see Wopereis et al., 1999). To avoid problems with spikelet sterility in the wet season, farmers need to transplant their dry-season crop in January, or latest February, to have ample time (at least 2 months) to prepare for the wet season. Most farmers indeed transplanted in February.

Spikelet sterility due to high daily maximum temperatures in the DS as reported from irrigated schemes further north (e.g. the Office du Niger in Mali; Dingkuhn and Sow, 1997) does not seem to be an important problem in the region. Nevertheless, farmers should establish the DS crop in January or until mid February latest since delayed start of the DS is in most cases directly related to a late start of the WS. RIDEV derived recommendations on optimal timing of crop management practices during the season (Table 2) can further contribute to higher fertilizer efficiency and should be part of integrated crop management options. Such approaches were successful in similar rice-based systems in West Africa (Kebbeh and Miézan, 2003).

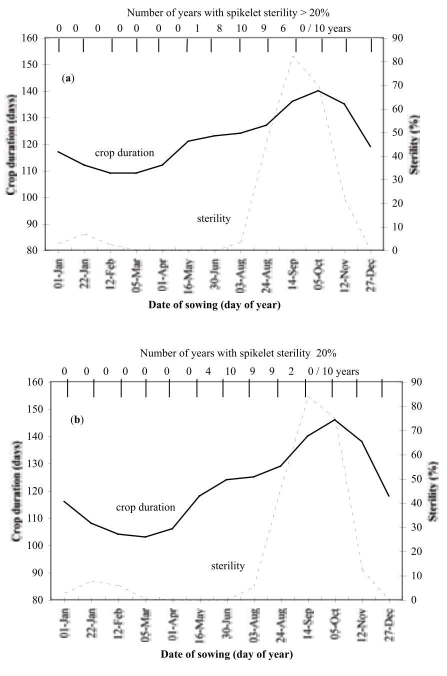

Figure 2. *Average spikelet sterility and crop growth duration of (a) FKR 19 (TOX 728-1) and (b) FKR 14 (4418) simulated with RIDEV using weather data from Fada N'Gourma and the years 1969-1979.*

Yields and yield gap estimation: Yields were highly variable in both seasons (Table 3). There was greater variability in TFyields (farmer's practices with fertilizer applied) compared to T0 yields (farmer's practices without fertilizer applied). For Kou Valley, dry season yields were relatively low, in contrario with Bagré. Farmers blamed this on unreliable irrigation water supply. In Kou Valley, the maximum attainable farmers' yield in the study of Wopereis et al. (1999) and in that of Nebié (1995) was 7-7.5 t ha^{-1}, indicating yield gaps between actual and attainable yield ranging from 0.6 to 5.7 t ha^{-1}. The same trend was observed in Bagré, where yield gap varied between 3.0 to 4.3 t ha^{-1} (Segda et al., 2004). Best farmers' yields were high above farmers' average yields in both seasons, indicating a considerable yield gap. This yield gap as well as the regular occurrence of almost complete crop failure confirmed reports by Wopereis et al. (1999) and Haefele et al. (2001, 2002) for other irrigated systems in West Africa. The contribution of late sowing in the WS to the yield gap was discussed above. In addition, suboptimal crop management contributed to the yield gap in both seasons.

Table 3: Descriptive statistics of (i) average grain yield of unfertilized plots (T0), farmers' practice (TF), increase in grain yield, and (ii) on indigenous nitrogen supply and N-use efficiency in farmers' fields, based on the 1995 WS - 1996 DS (Kou Valley), and 1999 DS – 2000 WS (Bagré).

		Kou Valley			Bagré		
		Mean	Min	Max	Mean	Min	Max
T0 yield	(t ha^{-1})	3.2 (0.8)	1.7	4.3	1.9 (1.1)	0.6	4.8
TF yield	(t ha^{-1})	4.5 (1.2)	2.7	6.7	3.6 (1.7)	1.0	7.8
Increase in grain yield (TF – T0)	(t ha^{-1})	1.3 (0.8)	0.03	2.9	1.7 (0.8)	0.4	3.1
INS	(kg N ha^{-1})	51 (7)	20	83	37 (23)	9	102
RFN	(%)	32 (14)	-11	107	37 (18)	13	77
IEN	(kg grain per kg nutrient uptake)	53 (10)	-13	122	46 (10)	26	62
PFP_N	(kg grain per kg N applied)	60 (16)	21	127	35 (12)	16	52

In brackets ( ) are standard deviation

Adapted from Wopereis et al. (1999) for Kou Valley and Segda et al. (2003, 2004) for Bagré;

INS: indigenous soil nitrogen supply in farmers' fields; RFN: recovery fractions of applied N fertilizer; IEN: internal efficiency for N; PFP_N: partial factor productivity of nitrogen; DS: dry season; WS: wet season

Indigenous nitrogen supply and N-use efficiency: In both sites, aboveground plant N uptake in T_0 plots was used to estimate indigenous soil N supply (INS), assuming that in most unfertilised soils N is the most limiting element for crop growth. Soil N-supplying capacity (Table 3) varied widely across survey sites (9-102 kg N ha^{-1} in Bagré, and 20-83 kg N ha^{-1} in Kou Valley), and farmers did not adjust quantities of fertilizer N to indigenous soil nitrogen reserves. Rapid and reliable techniques are needed to adjust the total dose of applied fertilizer N to the indigenous soil N-supplying capacity. INS values observed indicated higher values in Kou Valley than in Bagré (average 51 kg N ha^{-1} vs 37 kg N ha^{-1}).

The internal N use efficiency (IEN) for the 2000 wet season in Bagré is presented in Figure 3a, showing a linear relation between plant N uptake and yield. Envelope lines of maximum dilution and accumulation of N in modern rice cultivars according to Witt et al. (1999) were added and reveal N accumulation for T_0 plots (average IEN of 51 kg grain kg^{-1} N uptake) and T_F plots (average IEN of 48 kg grain kg^{-1} N uptake). In Kou Valley, IEN varied from -13 to 122 kg grain per kg Nean: 53). Both values are rather low if compared with average IEN data reported by Witt et al. (1999) who found average values of 69 kg grain kg^{-1} N uptake in plots without N application and 59 kg grain kg^{-1} N uptake in N fertilized plots. Identical observations were made by Haefele et al. (2001, 2003a) in the Sahelian West Africa. Low internal efficiency of nitrogen in the WS indicate that either nutrients other than N were limiting yield (e.g. P or K) or that yield was reduced by other factors (spikelet sterility, weed competition, pest and diseases). Since considerable P and K doses were applied, the latter explanation seems more likely.

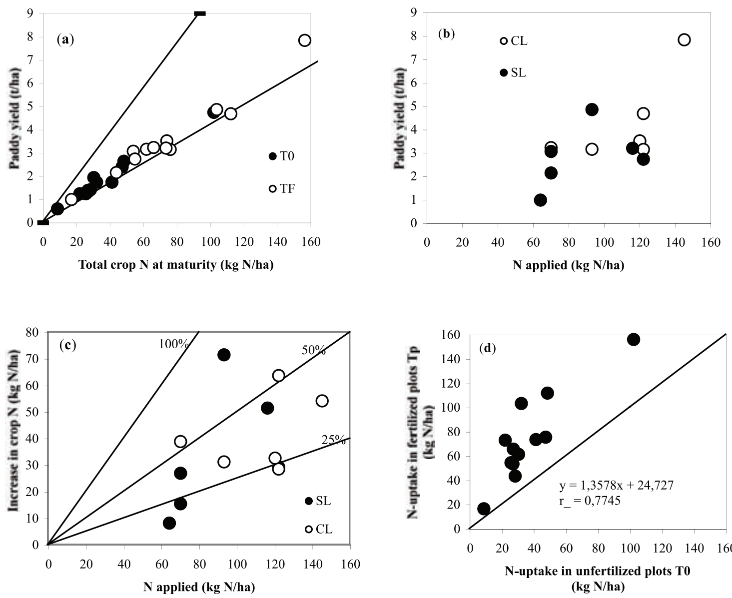

Figure 3. *Characteristic features of indigenous and applied nitrogen in farmers' fields during the 2000 wet season in the Bagré irrigation scheme (Burkina Faso). The relation between grain yield and N-uptake in fertilized (TF) and unfertilised plots (T0) is shown in Figure* **3a**. *Shown are also the relation between farmers' yield and N-dose applied (***3b***) in sandy loam (SL) and clay loam (CL) soils; the recovery rate of applied fertilizer N (***3c***) in SL and CL soils; and (***3d***) the relation between N absorbed in fertilized (TF) and unfertilized plots (T0)*

Although the relation between N uptake and yield was strong, no relation was found between the quantity of N applied and observed grain yield (Figure 3b), neither for clay loam nor for sandy loam soils. Partial factor productivity of N (PFPN) varied from 16 to 52 kg grain kg^{-1} N applied with an average of 35 kg grain kg^{-1} N applied. Observed PFPN values demonstrated the variability of efficiency, e.g. one farmer achieved a yield of 3.2 t ha^{-1} by applying 70 kg N ha^{-1} whereas another farmer applied

122 kg N ha^{-1} to yield only 2.7 t ha^{-1}. These differences can largely be explained by highly variable fertilizer N recovery rates.

For Bagré, N recovery rates (Figure 3c) ranged between 7 to 77% of applied N, with an average of 37%; indicating that 63% of the fertilizer applied to the plant was lost. Only three farmers achieved more than 50% recovery of applied N, whereas all other farmers had recovery rates between 10 and 50%. No influence of soil texture type on N recovery was detectable. The observed average recovery rate is at the lower end of the range reported for other Sahelian rice growing environments by Wopereis et al. (1999) and Haefele et al. (2000, 2001, 2002, 2003a) and was similar to values reported by Cassman et al. (1997) for Asia. Fertilizers account for 32% of total production costs in irrigated rice system in Bagré (Table 4). Improving the recovery of fertilizers will often increase yields, without major changes in input levels (Segda et al., 2005).

Noteworthy is the observed relation between T_0 yields and T_F yields, which is mirrored by the relation between plant N uptake in T_0 and T_F plots (Figure 3d). It could be concluded, that the yield gain due to fertilizer application is mostly related to natural soil fertility and only modulated by crop management dependent fertilizer recovery rates. This would make indigenous soil fertility the decisive factor for yield and fertilizer response given a range of crop management practices. It would also explain the absence of a relation between N applied and yield or increase in crop N (Figure 3c).

Farmers' perceptions: Farmers' main concerns at the end of the 2003 dry and wet seasons (Figure 4) were (i) access to, and high cost of fertilizer, (ii) sale of paddy and (iii) soil management (labour). Financial constraints such as access to credit was also been mentioned. Post-harvest surveys were instrumental in deriving farmers' perceptions of their major constraints. During the 1999 dry season and the 2000 wet season, their mains concerns were accessibility to fertilizer and marketing of paddy. Because of difficulties in marketing the harvested product, they could not reimburse their debt in time and financial constraints became farmers' main concern.

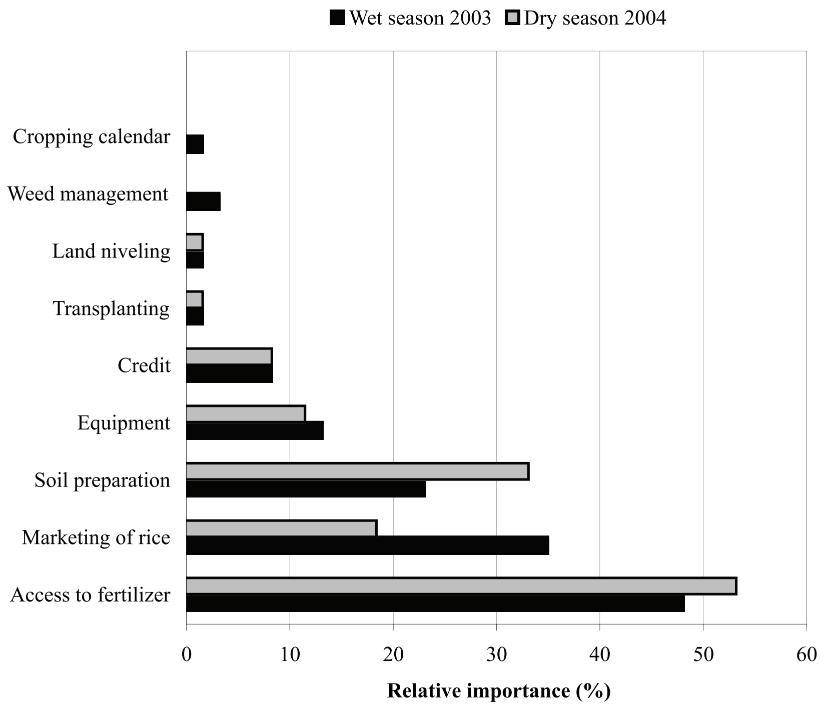

Figure 4. *Farmers' perceptions of major constraints in irrigated rice cropping in Bagré irrigation scheme during wet and dry seasons. Shown are average values for all farmers and all constraints mentioned.*

Economic analysis: The majority of farmers had positive net returns, and average total budget value/cost ratios were 1.2 in the WS and 2.1 in the DS (table 4). Partial budget analysis of fertilizer use (Table 4) revealed considerably lower value/cost ratios of fertilizer use in the wet season (mean V/C: 1.5) compared to the dry season (mean V/C: 2.9) in Bagré (Segda et al., 2004). Negative net returns occurred more frequently in the WS (3 out of 12 farmers), but concerned also 2 out of 16 farmers in the DS. In the WS, two-thirds of farmers had net benefits below 131 US $ per season (Figure 5).

Table 4: Average production costs and some elements of total and partial budget analysis for farmers participating in the surveys during the 1999 dry season and the 2000 wet season in the Bagré irrigation scheme (Nimatoulaye, Burkina Faso).

	1999 dry season		**2000 wet season**	
	US $ per ha^{-1}	%	US $ per ha^{-1}	%
Average production costs				
Fertilizers	163	34.4	160	31.0
Water	95	20.2	58	11.2
Credit reimbursement	39	8.3	51	9.9
Crop establishment	32	6.8	44	8.6
Soil preparation	32	6.8	38	7.5
Threshing	24	5.2	35	6.9
Harvesting	24	5.1	38	7.4
Weeding	22	4.7	38	7.3
Sacheries	19	4.1	22	4.4
Seeds	17	3.5	16	3.2
Fertilizer application	4	0.9	3	0.6
Chemicals	-	-	9	1.7
Chemical application	-	-	2	0.3
Total budget analysis				
Total cost	472		515	
Total revenue	962		642	
Net benefit	490		127	
Value / cost ratio	2.06		1.24	
Partial budget analysis for fertilizer use				
Treatment related cost*	224		197	
Gross added product	640		303	
Added net benefit	416		106	
Value / cost ratio	2.86		1.51	

** Includes costs of fertilizers and their application, as well as the costs for threshing, harvesting, and bagging of the yield increase caused by fertilizer use*

Rice cropping was more beneficial in the DS, were about 80% of the farmers had medium to high net benefits. Since average T0 yields were almost identical in both seasons (data not show), low net benefits in the WS were mainly due to low returns to fertilizer use as indicated by the low value/cost ratio in the partial budget analysis (Table 4). In Kou Valley however, wet-season net returns from fertilizer application were twice those of the dry season, due to higher recovery rates of N and higher average yields (see Donovan et al., 1999). As noted by the same authors, the dry season has higher agronomic yield potential due to greater solar radiation, but water shortages in plots more distant from the main canal resulted in low yields.

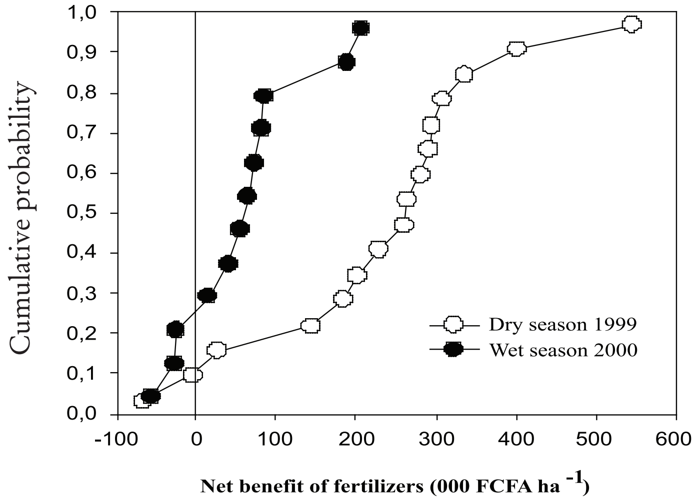

Figure 5. *Cumulative distribution functions of net returns to fertilizers for farmers in Bagré during the 1999 dry season and 2000 wet season. The vertical axis shows the cumulative probability of having the corresponding level of returns.*

Fertilizer and irrigation costs represented about 50% of total production costs, and are a major investment for the surveyed small-scale farmers. Due to high production costs and low yields, several farmers had low or negative returns to rice cropping. Net returns might have been underestimated due to the use of hired labour wage rates in the economic analysis, especially for farmers relying heavily on "cheap" family labour. Nevertheless, this does not affect the general trend of low net returns in the WS caused mainly by lower yields and a lower paddy price after the WS (Table 4 and Figure 5). Since most of the production cost items in the WS cannot be reduced substantially and significant paddy price increases cannot be expected, higher input use efficiency must be achieved to make the WS rice crop economically sustainable. The most promising ways to achieve this efficiency increase is (i) to avoid seeding after 15 August, (ii) to improve timing and quality of crop management practices, and (iii) to improve existing fertilizer recommendations. Especially continuous high doses of P and K fertilizer do not seem to be necessary at the current WS yield level. Validation of the simulation model RIDEV for site-specific cultivars could contribute to improved crop management planning in the region.

Developing site-specific nutrient management recommendations. The case of Bagré irrigation scheme

To improve existing crop and nutrient management recommendations and practices, an integrated approach is vital, taking the farmers' socio-economic as well as bio-physical environment into account. Nutrient management for rice should focus on developing fertilizer recommendations for spatial domains with relatively uniform agro-ecological characteristics, cropping practices, and socio-economic conditions (Dobermann et al., 2002; 2003a and b).

To reach that goal with agronomic trials is rather costly and time consuming, and simulation tools are increasingly used as a complement (Smaling and Janssen, 1993).

A framework for improved soil fertility management presented by Haefele et al. (2003b) was used. This approach combines field data with simulation tools in a flexible framework. It helps the user to diagnose limiting factors as well as to develop soil fertility management strategies as a function of his or her goals, e.g. profit maximisation, yield maximisation or minimising risk, given biophysical and socio-economic settings. We intended to: (i) estimate climatic risk in Bagré for the two rice growing seasons and for different crop establishment modes and dates, (ii) develop agro-economically sound fertilizer recommendations for a range of target yields, and (iii) evaluate such model-based alternative recommendations in farmers' fields.

RIDEV simulations: Table 5 shows optimal practices according to RIDEV for rice cultivar TOX 728-1. Mean values for simulations conducted at 7-days intervals over a period of 10 years are presented. The simulations address the dominant crop establishment techniques in each season, which is direct seeding in the dry season and transplanting in the wet season (Segda et al., 2004). The table shows best timing of crop management interventions as a function of sowing date (or transplanting) and indicates the risk of temperature induced yield losses. Transplanting after August 3 must be avoided. Assuming a preparation phase of about one month for the wet season and dry season crop duration of 120 days, the dry season crop should be established by mid February latest to avoid dangerous delays of the onset of the WS. The wet season crop could then be harvested beginning of December.

Alternative fertilizer recommendations: To derive alternative fertilizer recommendations (AFR), FERRIZ simulations were conducted based on the indigenous supply of 35 kg N ha^{-1}, 18 kg P ha^{-1} and 100 kg K ha^{-1}, obtained from the nutrient-omission trial (Segda et al. 2004); fertilizer recovery rates of 0.45 kg kg^{-1} for N, 0.25 kg kg^{-1} for P, 0.45 kg kg^{-1} for K, and Y_{pot} of 8.0 and 9.0 t ha^{-1}. Urea (46% N) and "cotton" fertilizer (12% N, 10.5% P and 10% K) were used in the simulations (Tables 6 and 7), as these fertilizers are commonly used by farmers in the region.

Maximum target yields were set to 80% of potential yield as beyond that level, internal efficiencies of nutrients in the rice plant decline (Witt et al., 1999). About 80% of potential yield seems also to represent a ceiling for what can be achieved by best farmers under field conditions (Dobermann et al., 2002).

For the same target yield, higher fertilizer doses have to be applied when Y_{pot} is lower (Table 6). For high target yields, N, P and K have to be applied, whereas only N application is needed for low target yields. For optimal profit (marginal rate of return = 0), up to US$ 244 must be invested in fertilizer in the dry season, which is above the investment made by most farmers. According to the field survey, farmers in Bagré spend on average US$ 171 (maximum US$ 226) for total fertilizer costs (Segda et al., 2004). The comparison of applied N, P and K and aboveground plant uptake at the

Table 5. RIDEV estimated cropping calendars using 7 days intervals for direct-seeded (dry season) or transplanted (wet season) rice, cultivar TOX 728-1, Bagré (Burkina Faso).

Sowing date	Transp-lanting date	First weeding (DAS)	First urea split (DAS)	Second urea split (DAS)	Third urea split (DAS)	Flowering Date (DAS)	Date of last drainage (DAS)	Harvest date (DAS)	Spikelet sterility (%)	Risk of sterility > 20% (No. of years/10 years)
Direct seeding										
01 Jan		29	32	58	78	88	103	117	2.7	0
08 Jan		29	32	56	76	87	101	115	3.7	0
15 Jan		28	31	54	74	85	99	113	6.8	0
22 Jan		25	28	53	73	83	98	112	7.8	0
29 Jan		25	28	52	72	82	97	111	8.5	0
05 Feb		22	25	50	70	81	95	110	6.2	0
12 Feb		21	24	50	70	80	95	109	2.3	0
19 Feb		20	23	49	69	79	94	109	0.6	0
	*Transplanting**									
25 June	20 July	39	42	73	93	97	118	133	0.9	0
02 July	27 July	39	42	72	92	97	117	134	6.1	1
09 July	03 August	39	42	72	92	97	117	134	22.5	4
16 July	10 August	39	42	71	91	97	116	136	37.7	6
23 July	17 August	36	39	67	87	98	112	137	48.8	10
30 July	24 August	39	42	70	90	101	115	140	71.7	10
06 Aug.	31 August	39	42	71	91	104	116	143	72.9	10
13 Aug.	07 Sept.	39	42	72	92	108	117	146	84.4	10

** Transplanting is recommended 25 days after sowing DAS = days after sowing.*

Table 6. Simulated N, P and K requirements to reach specific target yields in the Bagré plain, depending on potential yield (Y_{pot}).

Y_{pot} ($t\ ha^{-1}$)	Target yield ($t\ ha^{-1}$)	Urea dose ($kg\ ha^{-1}$)	NPK dose ($kg\ ha^{-1}$)	NPK applied ($kg\ ha^{-1}$)			Nutrient uptake at target yield ($kg\ ha^{-1}$)			Fertilizer costs (US $ ha^{-1})
				N	P	K	N	P	K	
9.0	8.0	425	275	229	28.2	27.4	139	25.5	116	317
	7.5	400	150	202	15.7	14.9	127	22.2	111	248
	7.0	350	50	167	5.2	5.0	111	19.6	106	179
	6.5	275	0	127	0.0	0.0	93	18.3	104	123
	6.0	200	0	92	0.0	0.0	77	18.3	104	89
8.0	7.0	370	150	188	15.7	14.9	121	22.2	111	235
	6.5	300	50	144	5.2	5.0	101	19.6	106	157
	6.0	225	0	104	0.0	0.0	83	18.3	104	100
	5.5	175	0	81	0.0	0.0	72	18.0	104	78
	5.0	125	0	58	0.0	0.0	62	18.0	104	56

Included are yield levels (Y_{pot}). All data are based on simulations with FERRIZ_F using indigenous supply of 35 kg N ha^{-1}, 18 kg P ha^{-1} and 100 kg K ha^{-1} and fertilizer recovery rates of 0.45 kg kg^{-1} for N, 0.25 kg kg^{-1} for P, and 0.45 kg kg^{-1} for K. Average fertilizer prices are used for 2003-2004.

target yield indicates negative P and K balances for all simulation scenarios, when complete grain and straw removal is assumed (Table 7).

The outcome of the FERRIZ simulations illustrates the importance of N fertilizer as compared to P and K in Bagré. AFR were then derived based on estimated yield, NPK balance, costs and simplicity. We decided to reduce the NPK fertilizer dose as compared to existing fertilizer recommendations by 100 kg ha^{-1} and to increase the urea dose by 100 kg ha^{-1}. This does not entail increased costs but gives extra weight to N as compared to P and K.

AFR for the wet season were, therefore, defined as: 116 kg N ha^{-1}, 21 kg P ha^{-1}, and 20 kg K ha^{-1} and for the dry season: 139 kg N ha^{-1}, 21 kg P ha^{-1}, and 20 kg K ha^{-1}.

In order to compare the performance of the alternative recommendations versus the existing fertilizer recommendations (EFR), FERRIZ was used to simulate yield and plant uptake with the same input data as above. Simulation results are given in Table 7. Existing fertilizer recommendations differ for the dry and wet season (105 kg ha^{-1} N, 31 kg ha^{-1} P, and 30 kg ha^{-1} K in the DS; 82 kg ha^{-1} N, 31 kg ha^{-1} P, and 30 kg ha^{-1} K in the WS), assuming a lower yield potential in the WS, but reduces only the N dose. Simulated yields with the higher dose were about 6.5 t ha^{-1}, whereas the lower dose resulted in yield estimates of about 6.0 t ha^{-1}. Nitrogen and P uptake were always below the applied amount, whereas K uptake was more than three times higher.

AFR increased estimated yields by 0.4 to 0.5 t ha^{-1} as compared to EFR. The balance between nutrients applied and plant uptake became more positive for N, balanced for P and even more negative for K. Simulations were also conducted for DS growing conditions, using the AFR developed for the WS as farmers were reluctant to accept the 'high' AFR doses, they preferred to use AFR developed for the WS for both seasons. In this case AFR yields were comparable to EFR yields, but at substantially lower costs.

Validation experiments: The performance of existing and alternative fertilizer recommendations and farmers' practice were compared during the dry and wet seasons of 2003 and 2004 (Table 8). Farmers decided to test only the AFR developed for the WS in both seasons; AFR developed for the DS was considered not within financial reach of most farmers. The amount of fertilizer applied by the farmers themselves was indeed considerably lower than AFR and EFR rates. Farmers applied about 80 kg N ha^{-1}, 16 kg P ha^{-1} and 16 kg K ha^{-1}, but there was a large variability among farmers in terms of timing and dosage used (details not shown). Total fertilizer cost (TFC) was about US$ 54 ha^{-1} higher for AFR as compared to FP. TFC for AFR was substantially lower than EFR in the DS and about the same in the wet season. Gross returns above fertilizer cost (GRF) were most interesting for AFR, with differences between AFR and EFR ranging from US$ 99 to 202 per season, and between AFR and FP ranging from US$ 62 to 266 per season. Over the four seasons, EFR increased gross returns above fertilizer costs by an average of about US$ 162 per season as compared to both farmers' practice and actual recommendations.

Table 7: Simulated yields, yield gains and NPK uptake using alternative (AFR) and existing fertilizer recommendations (EFR) for the Bagré plain during the dry season (DS) and the wet season (WS).

Season*	Fertilizer recom-mendation.	Y_{pot}	Urea dose	NPK dose	N dose	P dose	K dose	Yield estimate	NPK uptake	Fertilizer costs	Yield gain (AFR-EFR)
		t ha^{-1}	-----------------kg ha^{-1}				----------------	--t ha^{-1}--	-----kg ha^{-1}-----	US \$ ha^{-1}	----t ha^{-1}----
DS	EFR	9.0	150	300	105	31.4	29.9	6.52	82/23.0/108	206	
WS	EFR	8.0	100	300	82	31.4	29.9	6.00	72/22.3/105	184	
DS	AFR	9.0	250	200	139	20.9	19.9	6.92	96/21.7/106	205	0.40
DS	*	9.0	200	200	116	20.9	19.9	6.56	86/21.3/105	182	0.04
WS	AFR	8.0	200	200	116	20.9	19.9	6.46	86/21.3/105	182	0.46

* AFR for wet season applied to dry season to save on fertilizer costs – as preferred by farmers in the validation trials

Target yields were simulated using FERRIZ_Y and average indigenous soil nutrient supply of the nutrient omission trial. Estimated total fertilizer costs were calculated using average prices in 2003-2004. Simulations were based on: indigenous supply of 34.6 kg N ha^{-1}, 17.6 kg P ha^{-1} and 99.7 kg K ha^{-1}: fertilizer recovery rates of 0.45 kg kg^{-1} for N, 0.25 kg kg^{-1} for P, 0.45 kg kg^{-1} for K.

Table 8: Effect of farmers' practice in terms of fertilizer use (FP), existing fertilizer recommendations (EFR) and alternative fertilizer recommendations (AFR) on paddy yield, total cost of fertilizer (TFC) and gross return above fertilizer cost (GRF) during the dry and wet seasons of 2003 and 2004 (DS03, DS04, WS03, WS04), Bagré, Burkina Faso.

		Treatments		
	Season	**AFR**	**EFR**	**FP**
Paddy yield				
(t ha^{-1})	DS 2003	5.77a	5.35a	4.03a
	WS 2003	6.50a	5.90a	5.92a
	DS 2004	7.48b	6.43a	6.33a
	WS 2004	6.01b	5.02a	4.53a
	Average*	**6.62**b	**5.79**a	**5.45**a
N_fertilizer uptake				
(kg N ha^{-1})	DS 2003	66	66	51
	WS 2003	108	87	85
	DS 2004	120	84	88
	WS 2004	87	79	68
	Average	**101**b	**81**a	**77**a
P_fertilizer uptake				
(kg P ha^{-1})	DS 2003	13	13	9
	WS 2003	18	19	17
	DS 2004	27	18	18
	WS 2004	19	18	16
	Average	**21**b	**18**a	**17**a
K_fertilizer uptake				
(kg K ha^{-1})	DS 2003	108	85	61
	WS 2003	138	129	118
	DS 2004	154	114	100
	WS 2004	112	95	86
	Average	**133**b	**109**a	**96**a
Total cost of fertilizer (TCF)				
(US $)	DS 2003	171	193	116
	WS 2003	173	177	132
	DS 2004	191	217	142
	WS 2004	191	193	132
	Average	**184b**	**197b**	**133a**
Gross return above fertilizer cost (GRF)				
(US $)	DS 2003	892a	793a	626a
	WS 2003	1023a	909a	958a
	DS 2004	983b	793a	852a
	WS 2004	1014b	812a	776a
	Average	**988b**	**828a**	**829a**

**Average= mean of the four cropping seasons (DS 2003 + WS 2003 + DS 2004 + WS 2004). N/P/K fertilizer use for EFR in DS: 105:31:30 kg ha^{-1}, in WS: 82:31:30 kg ha^{-1}; for AFR regardless of season: 116:21:20 kg ha^{-1}. See text for prices of fertilizer and paddy per season. Yield and GRF data followed by a common letter are not significantly different (Newman-Keuls test, p = 0.05, tests per season).*

The simulated yield and profitability gains were more than confirmed in farmers' fields during four consecutive growing seasons. In all seasons, AFR yields were considerably higher than EFR or FP yields, and yield gains were significant ($p<0.05$) in 2004 (Table 5). Yield gains from AFR were larger than simulated, probably because for AFR, fertilizer N was applied in three splits, ensuring better balanced crop nutrition as compared to farmer practice and EFR where only two N splits were used. Similar results were obtained by Wopereis-Pura et al. (2002). Monitoring INS, IPS and IKS every five to ten years with omission plots in farmers fields as proposed by Dobermann et al. (2003a) and the here presented framework may serve to readjust AFR in the future.

Conclusion

The reported results illustrate the multitude of factors influencing the performance of irrigated rice systems. Agronomic constraints were similar as found for other schemes analyzed in the region. Suboptimal timing of crop management practices was identified as an important cause for low productivity. Net benefits to irrigated rice cropping were mostly positive in the DS but often low or even negative in the WS. Yield gaps between average farmer's yield and best farmer's yield were high, indicating considerable scope for yield and profit increases in both seasons. Farmer's knowledge of existing recommendations was imperfect, partly explaining the non-adoption. However, the presented analysis of the rice cropping system strongly indicated that higher input use efficiency, higher yields, and higher financial returns can be achieved without additional investments. To reach these goals, a revision of existing fertilizer recommendations and improved information transfer (including decision support tools) to farmers and extension officers are necessary. At the scheme level, the supply and the accessibility of agricultural inputs, such as fertilizer need to be improved. To increase the competitiveness of locally produced rice vis-à-vis cheap imports, production costs per unit produced must be reduced or a higher quality product must be produced. There is a clear need to identify constraints and design solutions to speed-up technology transfer through collaborative assessment of existing technology, and training of key players in farmers' organizations, NGOs, and extension agencies. If farmers are given better access to information, rice technologies, inputs and decision making, rice production on irrigated land in West Africa may leap forward rapidly as potential production gains are still large.

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Chapter 10

Review of Work on Soil Phosphorus in Ghana

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Abstract

A review of work in Ghana on soil P reveals a low status of available P in most soils. This has been attributed in part to extensive losses due to long periods of intense weathering and strong fixation by iron and aluminium oxides prevalent in many soils in the country. Frequent burning of the vegetation also contributed to the degradation of the status of soil P. Low pH values of most soils also explain the observed trend. The soils vary in their P requirement, being higher for soils with very low pH and large amounts of free Al and Fe oxides. From the review, application of P has a significant positive effect on crop yield. Rates of P application differed depending on the crop and the condition of the soil. From the review, recommended methods of improving P availability for plant growth included: Application of large doses of P fertilizer to overcome fixation, Liming and lime-phosphorus combinations, Use of relatively insoluble sources (basic slag and phosphate rock) on very acidic soils, particularly for tree crops, Use of leguminous crops (cowpea) to solubilize relatively insoluble rock phosphate for maize production, Use of mycorrhiza in improving P use efficiency. The review also reveals the importance of evaluating various sources of P on soils of different properties since the effectiveness of a particular P source is related to the properties of the soil. The need to re-evaluate the appropriate P rates for various crops is recommended.

Key words: *Soil phosphorus, P availability, P fixation, Liming, Ghana*

Résumé

Au Ghana, un apercu des travaux sur le phosphore du sol revele une faiblesse du phosphore disponible dans le sol. Cet etat est attribue en partie aux pertes excessives due aux longues et intense periodes d'oxydation du fer et la prevalence des oxides d'alluminium dans la pluspart des sols du pays. Les feux de brousse ont aussi contribue à degrader la situation du phosphore du sol. Les valeurs faibles du pH de la pluspart des sol peut expliquer cette tendance. Les besoins en phosphore des sols varient selon que leur pH est faible ou eleve et selon leur degree d'oxydation en fer et en alluminium. Les doses de P appliqué different selon le type de sol et de culture. Dans cette revue, on note plusieurs methodes d'amelioration du P disponible pour le developpement des plantes y compris l'utilisation de fortes doses d'engrais phosphates pour contrer sa fixation, le chaulage et sa combinaison avec le phosphore, l'utilisation de sources de phophore peu soluble (phosphate naturel) sur les sols tres acides surtout pour les arbres, l'utilisation des legumineuses (niebe) pour solubiliser le phosphate naturel pour la production du maïs et l'utilisation des mychorise pour ameliorer l'efficacite d'utilisation du phosphore.Cette revue revele egalement l'importance de l'evaluation de diverses sources de phosphore sur des sols de proprietes differentes puisque l'efficacite d'une source de phosphore depend des proprietes du sol. Il est recommande de reevaluer les doses appropriees pour les divers types de cultures.

Mots clés: *phosphore*, *phosphore disponible, fixation du phosphore, Ghana*

Introduction

Phosphorus is an essential element in crop production. It plays an important role in crop maturation, root development, photosynthesis, N fixation and other vital processes (Bationo, 1997). As a nutrient it is second in importance only to nitrogen. In the soil, P is present in the soil solution, soil organic matter or occurs as inorganic P. Unlike nitrogen phosphorus can not be fixed from the atmosphere. It is generally regarded as the nutrient that is most limiting in tropical soils. The problem of P is three fold; the quantity of P in soils is low (200-2000 kg P ha^{-1} furrow slice) P compounds are generally insoluble and soluble P is rapidly adsorbed and becomes insoluble (Brady, 1990). Less than 1% of total soil P may exist as soluble P.

Generally phosphorus is present in the inorganic form more than the organic form. However, where the parent material is very low in phosphorus levels, organic sources may be of major importance as main source of P for plant growth (Brady, 1990).

In Ghana, studies on soil phosphorus started between the late forties and early fifties. Much of the early information on soil phosphorus was obtained through regional soil surveys (Adu, 1969; Adu, 1992, 1995a, 1995b; Adu and Mensah –Ansah 1995; Nye and Bertheux, 1957; Oteng and Acquaye, 1971). Studies on the effect of P on crop yield started receiving attention in the sixties and seventies. Much of the focus was on the determination of appropriate rates for various crops (Soil Research Institute, 1964; Ofori, 1965), problems associated with fixation (Soil Research Institute, 1975), methods of extraction (Halm, 1964) and the importance of various sources of P on crop performance (Ofori, 1966).

Most soils in Ghana have low capacity to supply P for plant growth. This inability to supply adequate amounts of P for plant growth is partly due to extensive losses due to long periods of intense weathering and strong fixation by Al and Fe oxides prevalent in many soils (Abekoe, 1998; Doe, 2006). Frequent burning of the vegetation also contributes to the degradation of P status in Ghanaian soils since some of the ash is blown away by wind. Continuous cropping with little or no fertilization further enhances P depletion. According to Rhodes (1995), in Ghana, total crop uptake over

10 years were 428,700 t nitrogen, 73,100 t phosphorus and 414,900 t potassium with over 50% of these nutrients in the grain and other edible parts.

Single Super Phosphate (SSP) and Triple Super Phosphate (TSP) are the major commercial sources of P fertilizer in Ghana. Other traditional sources include rock phosphate, basic slag, oil palm bunch and cocoa husks (Owusu Bennoah, 1997). Farmers also use large amounts of organic manures (poultry manure, cow dung etc.) which contain adequate amounts of P.

This review examines the status of P in Ghanaian soils, problems associated with P availability, studies on the effect of P on crop growth and recommended soil management to improve P availability for crop production.

Distribution of major soils and their P status

The Ghanaian classification (Brammer, 1962) was equated to the World Reference Base (WRB) classification, ISSS/ISRIC/FAO (1998) by Adjei-Gyapong and Asiamah (2000) as follows:

Savanna Ochrosols (WRB: Lixisols/Luvisols) – These soils occur in northern Ghana and parts of the coastal savanna. They are highly weathered and moderately to strongly acid in the surface soil. Organic matter is low (>15 g kg^{-1} soil). Soil fertility is generally low. Available P mostly ranged between trace and 2.0 mg P kg^{-1} soil.

Forest Ochrosols (WRB: Acrisols/Alisols/Lixisols/Ferralsols/Nitisols/Plinthosols)- These soils occur within the forest zone and parts of the forest-savanna transition. They are deeply and highly weathered and generally moderately to strongly acid in the surface soil. The soils have high organic matter content in the top horizon which may contribute significantly to the P pool. Soil fertility is generally low with available P values mostly between 1.0 and 5.0 mg P kg^{-1} soil.

Forest Oxysols (WRB: Ferralsols/Acrisols)- These occur in the high rainfall zone (south-west of Western Region). Soils are deeply and highly weathered. The soils are strongly acid (pH<5.0). Organic matter is very high with high potential in P supply. P fixation is very high due to the presence of large amounts of Al and Fe oxides. Available P values mostly range from trace to 2.0 mg P kg^{-1} soil.

Groundwater Laterites (WRB: Plinthosol/Planosol)- These soils occur mostly in northern Ghana. They are shallow to plinthite and low in organic matter. Soil fertility is generally poor. They have high P fixation due to the presence of abundant iron concretions. The soils are generally low in available P.

P status in Ghanaian soils

Soil P (total and available P) varies markedly between agro-ecological zones and within agro-ecological zones. Available P status is generally low in Ghanaian soils. Levels of total and available phosphorus of some major soils in Ghana are presented in Table 1. Total phosphorus is considerably lower in the savanna than the forest soils (Adu, 1969; Adu, 1992, 1995a, 1995b; and Adu and Mensah–Ansah, 1995). These studies were carried out during the late forties and late sixties. Information from current studies show a marked difference in available P across the country (Adjei-Gyapong and Senayah, 2001; Dedzoe et al., 2004; Senayah, 1994; Tetteh and Dedzoe, 2004; Tetteh et al, 2002). At Bogoso in the Western Region, Tetteh and Dedzoe (2004) obtained available P values ranging from 0.4 to 2.7 mg Pkg^{-1} soil. Soil pH of all the 42 soil samples collected by Tetteh and Dedzoe (2004) were below 4.5. Tetteh et al, 2002 also obtained very low values of available P (trace – 1.2 mg Pkg^{-1} soil) when evaluating soil chemical properties of Benso Oil Palm Plantation in the Western Region. Soil pH of most of the soil samples ranged below 5.0. At Bawjiase in the Central Region, mean available P was 8.0 mg Pkg^{-1} (2.3 – 23.6 mg Pkg^{-1} soil) when soil chemical properties of a pineapple farm was examined Dedzoe et al, 2004. Soil pH values of the same Bawjiase soil samples ranged from 5.3 – 6.7. Adjei-Gyapong and Senayah (2001) obtained a range of 5.1-11.5 $mgkg^{-1}$ P at Asubima forest within the semi-deciduous forest in the Brong Ahafo region. Soil pH was above neutral. Buri et al (2001) evaluated soil fertility status of some lowlands in Ghana and reported generally low levels of available P. Studies in parts of Northern, Upper West and Upper East regions show that available P is very low ranging from trace to 6.0 mg Pkg^{-1} soil (Adu, 1969; Senayah, 1994; Senayah et, al 1998, Issaka et al, 2004; Dedzoe et al, 2002).

Table 1: Selected soil properties (surface soil) of some major soils in Ghana

Soil series	Location	Soil pH	Organic Matter (%)	Available P (mg kg^{-1}) Bray 1	Total P (mg kg^{-1})
Varepere (Ferric Luvisol)*	Lawra	7.5	0.48	nd	30[2]
Damongo (Ferric Lixisol)	Ejura	7.3	1.07	nd	134[3]
Kpelesawgu (Eutric Plinthosol)	Tamale	6.7	1.86	nd	108[4]
Bekwai (Ferric Acrisol)	Kwadaso	5.2	8.89	nd	391[1]
Lima (Ferric Planosol)	Tamale	5.1	1.2	2.6	nd[5]
Bediesi (Rhodic Lixisol)	Asubima	7.6	2.6	5.1	nd[6]

nd=not determined

*Source: [1] Adu, 1992, [2]Adu, 1995; [3]Adu, Mensah-Ansah, 1995; [4]Adu, 1995; [5]Dedzoe (2002); [6]Adjei-Gyapong and Senayah (2001) * WRB (ISSS/ISRIC/FAO,1998)*

In terms of absolute values available P is very low in most parts of the savanna agro-ecology and parts of the Western regions (ranging from trace to 2.0 mg P kg^{-1}). Values for the semi-deciduous-forest, forest-savanna transition and the forest zones are relatively better (ranging from 2.0 to 6.0 mg P kg^{-1}). This review clearly shows that P is a major problem in most Ghanaian soils. Use of mineral fertilizer is low (Doe, 2006) and is a major factor in crop yields being poor. Additions of P and/or management practices that will allow P to be more available are important in increasing production. However, focus should be more on addition of P since most soils have poor P reserves.

Influence of P on crop production

As a major plant nutrient which is deficient in most soils in Ghana, P application has a positive effect on crop production if nitrogen and other nutrients are not limiting. According to Owusu-Bennoah (1997), the potential of crop production in Ghana far exceeds the current production levels. He attributed the low crop yields to low soil fertility as the major cause.

Crops generally differ in their P requirements and therefore respond differently when P is applied. The major soils in Ghana (Savanna Ochrosols, Forest Ochrosols, Forest Oxysols and Groundwater Laterites) have different P requirements. Some of these soils have high P adsorption capacities due to the presence of large amounts of Al oxides and/or Fe oxides (Lathwell, 1979; Abekoe and Tiessin 1998) and hence may require higher rates of P application. In P adsorption and desorption studies on seven rice growing soils, the amount of P added to obtain equilibrium solution concentration of 0.2 mg P L^{-1} varied from 42 to 175 mg P L^{-1} across all soil types (Lathwell, 1979).

Effects of P on crop production in Ghana have been reported by several authors (SRI, 1963, 1964; Ofori, 1963a, 1963b, 1963c, 1965, 1966; 1972, 1975; Lathwell, 1979; Nyamekye, 1989; Issaka et al, 2003, Buri et al, unpublished; Tetteh et al unpublished). According to them P generally has a positive influence on crop yields. These authors observed that initial soil P and soil properties such as pH, Al and Fe oxides affect the response of crops to applied P. In a long-term trial, continuous cropping for 10 years without any P addition resulted in very poor crop growth (SRI, 1963). During this period, response to commercial P fertilizers and mulch were significant.

Cereals: In limiting nutrient studies on four soil series in the Central Region, P addition gave a range of 3.2 – 44.0% increase in maize yield over control (Table 2). Studies on sources and rates of P on maize grain yield clearly showed a significant increase in maize yield when P was applied (Ofori,1965 and 1966). This author observed that at Huhunya where the soil pH was about neutral, the order of increasing significance on yield was Basic slag < TSP = SSP. However at Oda where the soil was acidic (pH< 5.8), the order was TSP = SSP < Basic slag. Thus, the importance of a P fertilizer source varies depending on soil pH and other soil properties (Al and Fe oxides) that influence soil acidity. Soil pH exerts a strong influence on phosphate rock dissolution (Bolan and Hedley, 1990). Sanchez and Uehara (1980) stated that the solubility of phosphate rock depends on the fineness, time of reaction and soil pH. Basic slag is more soluble under acidic condition releasing Ca, P and other nutrients hence it is more effective when the soil pH is low. The material is, however, less effective when the soil pH is neutral due to low solubility. TSP and SSP are readily available and more effective under neutral conditions, these sources of P are less effective when the soil pH is low due to fixation by Al^{3+} and/or Fe^{3+} oxides.

Table 2: Effect of P on maize yield (t ha^{-1}) on some major soils in the Central Region

Soil series	Avail. P (mg kg^{-1})	80-0-40 kg NPK ha^{-1} (t ha^{-1})	80-40-40 kg NPK ha^{-1} (t ha^{-1})	% increase over control
Nta (Eutric Arenosol)	7.2	3.1	3.2	3.2
Asuansi (Ferric Lixisol)	8.5	2.9	3.7	27.6
Kumasi (Ferric Lixisol)	5.7	2.5	3.6	44.0
Bekwai (Ferric Lixisol)	3.4	3.3	3.7	12.0
Adeiso (Ferric Lixisol)	6.4	2.2	3.1	40.9

Source: SRI, 1974

According to Ofori (1965 and 1966), with the more soluble P sources (TSP and SSP), it is better to apply 72 kg P ha^{-1} (annually) only in the first season. For Basic slag, high application of 144 kg P ha^{-1} every two years gave the best results. Basic slag requires adequate time to solubilize before P can be made available. This explains the findings of Ofori (1965 and 1966). At Kwadaso and Huhunya Lathwell (1979) observed a significant increase in maize yield when P was applied. The author did not obtain any difference between the methods of P application (band and broadcast) on maize yield. No difference was observed between the lowest rate (76 kg P ha^{-1}) and the highest (211 kg P ha^{-1}). In a separate study at Kwadaso and Aiyinasi, Lathwell (1979) observed a significant increase in maize yield when both liming and P were applied. According to the author, effect of P decreased with increasing lime rate. At both sites, liming at 1.0 tha^{-1} and application of P at 22 kg P ha^{-1} were sufficient to improve maize yield. In the savanna zone, del Gindice (1989) used 20 kg P ha^{-1} as the recommended rate on maize. Nyamekye (1989) observed increased in maize yield when 25 kg P ha^{-1} was applied and grain yield remained constant up to 100kg P ha^{-1}. According to Nyamekye (1989) broadcast before ridging, broadcast and incorporation with a hoe and banding gave higher maize yield than ridging with spot application. Broadcast probably allowed more of the nutrient to be intercepted by plant roots since P is not mobile (Bationo, 1997).

Issaka et al (2003) applied relatively insoluble Togo rock phoshate (TRP) on a leguminous crop (cowpea) in the minor season (the short rain season) and compared its residual effect with SSP on maize in the major season (the long rain season). Maize grain yield under TRP was significantly higher than the control and similar to

SSP in the second year. The authors observed that application of at least 800 kg Togo rock phosphate ha^{-1} (broadcast) to cowpea is sufficient to improve soil P for maize production. Maize performed better when rotated with cowpea than continuous cropping when Volta phosphate rock was used as P source (Horst and Hardter, 1994). Thus the role of a legume (cowpea) in improving the availability of P from a relatively insoluble source (rock phosphate) is important in making P available for maize or other cereals. According to IFDC (1984) many Africa phosphate rock are low in chemical reactivity and are unsuitable for direct application. Legumes generally enhance phosphate rock dissolution through the creation of excess cations over anions (Flach et al, 1987). This ability of legumes explain why when cowpea is included in the rotation soil P is improved for maize production. In a study to develop fertilizer rate for maize production in Ghana, Tetteh et al (unpublished) recommended 26kg P ha^{-1} as the ideal rate for maize nutrition in southern Ghana.

Asubonteng (1997) observed a significant increase in rice yield when he applied Togo rock phosphate (TRP). He observed that rice yield under TRP was similar to that under TSP. According to him, use of cheap rock phosphate should be considered. Earlier studies at Ohawu showed a significant increase in paddy yield when the crop was fertilized at 48-21-40 N-P-K kg ha^{-1} ratio (Ofori, 1963b). Even though initial P was low, lower rates of P application gave better responses. In a recent response curve study (Buri et al, unpublished) paddy yield increased significantly up to the 26 kg P ha^{-1} rate and became constant up to the 53 kg P ha^{-1}. The authors proposed 26kg P ha^{-1} as the optimum for rice.

For the two major cereals (maize and rice) 26kg P ha^{-1} is the current recommendation. The difference in rates of P reported may be directly linked to the type of soil since soils differ in their fixation capacity. Practically, however, most farmers apply far less than this value and sometimes apply only nitrogen in the form of ammonium sulphate or urea. Low crop yield can generally be attributed to non or very low application of phosphorus fertilizers.

Grain legumes: Soya bean responded positively to P application resulting in significant increase in grain yield (SRI, 1975), with 41kg P ha^{-1} giving the most economical rate. At Nyankpala in the savanna zone grain yield of soya bean increased when 25 kg P ha^{-1} was applied, yield did not increase with increasing rates (Nyankpala Agricultural Station, 1989).

Phosphorus application in Bawku gave significant increase in groundnut kernel yield over control. Application of P at 11kg P ha^{-1} and 22kg P ha^{-1} gave similar kernel yield (SRI, 1988). According to the report, SSP gave better results than TSP. Kwakye, (1974) also reported on the significant effect of P on groundnut at Peki. The author obtained significant increase in kernel yield when fertilizer was applied at 48-16-30kg ha^{-1} N-P-K. Lathwell (1979) observed a significant increase in cowpea yield when P was applied at 11kg P ha^{-1}. Liming at 1.0tha^{-1} with application of 11kg P ha^{-1} was most economical. The response to applied P decreased with increasing lime rate. According to Dennis (personal communication) 13kgPha^{-1} is the appropriate recommendation for both cowpea and groundnuts.

Legumes perform better when P is applied. SSP may give better yield than TSP due to higher amounts of calcium in SSP. Soil with low Ca therefore reacts better when SSP is applied.

Root and tubers: Working at Ejura and Atebubu, Kwakye (1974) obtained significant increase in yam tuber yield when P was applied at 32kg P ha^{-1}. He recommended a complete fertilization of 96-32-40 kg ha^{-1} N-P-K for both sites. Buri and Issaka (2003) observed significant increase in tuber yield of yam when fertilizer was applied at 15-7-17 kg ha^{-1} N-P-K. According to these authors the importance of P varied according to varieties. While the yield of Puna (local name) was seriously affected by the absence of P it was slightly so with Dente (local name). Both varieties are white yam (*D. rotundata*). . From their study, Buri and Issaka (2003) recommend a fertilizer rate of 30-13-33kg ha^{-1} N-P-K.

Application of 13kg P ha^{-1} on cocoyam doubled cormel yield (SRI, 1988). In a limiting nutrient study at Manga on a Savanna Ochrosol, Issaka et al, 2002 observed that P was the nutrient that affected tuber yield of sweet potato most. In the absence of P, tubers were generally very small, both tuber and vine yields were significantly affected. Tuber yield was highest at 20 kg P ha^{-1}.

Using 2 local and 3 exotic cassava varieties and at four sites, Issaka et al, (in press) observed fertilizer rate of 60-26-50kg ha^{-1} N-P-K as the rate that gave significant higher root yield than the lower rates (0-0-0 and 30-30-30g ha^{-1} N-P-K) and similar to the higher rates (90-40-75 and 120-53-100kg ha^{-1} N-P-K). According to them response to fertilizer application was better with the exotic varieties.

Phosphorus is important in root initiation and maturity, nutrient imbalance may result in low tuber yield and poor quality.

Cotton: Cotton responded positively to P application (32 kg P ha^{-1}) at Kwadaso. P also interacted with NK to increase yield (SRI, 1966). 25kg P ha^{-1} was the recommended rate in the Savanna zone (Nyankpala Agricultural Station, 1989).

Tree crops: Application of P to coffee gave significant yield increase (>30% over control) in the third year of successive application (Ofori, 1966). According to the author SSP performed slightly better than TSP. In Ghana, tree crops (cocoa in particular) are usually not fertilized. According to Appiah et al. (1997), within a period of 10 years (1982-1992), through the harvested cocoa beans alone 76,000, 4,700 and 18, 000 tonnes of NPK were removed from the soil. The non-use of fertilizer is seriously affecting the fertility of the soil and hence the sustainability of cocoa production. In an incubation study, application of cocoa leaf litter alone did not affect bicarbonate-extractable inorganic P, but large initial increase of the inorganic P occurred when the litter was combined with P fertilizer (Ofori-Frimpong et al, 1997).

According to the authors the P content of the microbial biomass should be considered in determining the trend of organic P mineralization in soils. The need to manage residue from cocoa trees for nutrient recycling is important. Studies on the use of Togo rock phosphate on cocoa will provide another option for improving its production. Studies on the use of Togo rock phosphate on oil palm are on-going. Rock phosphate may improve not only the P status but soil pH and exchangeable bases since these contain large amounts of calcium and magnesium (Issaka et al. 2003).

P availability in soils and management

Apart from the low 'native' P status, several factors play a role in P availability and hence crop growth. Phosphorus in solution may be adsorbed or form compounds of iron or aluminium. The presence of free Al and Fe oxides in many of the Ghana's cropland soils is of significant importance regarding P availability. In Table 3, the presence of large amounts of free Al oxide and Fe oxide in Wenchi series resulted in less than 5mg P kg^{-1} P remaining in the soil solution after equilibration with 20 mg P ml^{-1}. Ahenkorah (1968) observed a significant correlation between P-retention and factors such as Fe, clay and organic matter content on some Ferralsols and Acrisols. According to Abekoe and Tiessin (1998), P deficiency is widespread in most soils of northern Ghana, and ferruginous nodules contained in some soils in the region accentuate the deficiency problems because they act as P sinks. Ferruginous nodules are present in many soils in Ghana and constitute a major problem in P nutrition. A review of soil characteristics of selected acid soils of south-western Ghana confirmed the high acidic and adsorption nature of the soils (Owusu-Bennoah and Acquaye, 1994). According to the authors, available P seems to be a major problem in these soils. Generally, depending on the crop type, low soil pH retards crop growth and ultimately crop yield. Many soils in the country are acidic and more are becoming acidic due to continuous cultivation and the use of acid forming fertilizers for example sulphate of ammonia (Buri et al, 2005).

Table 3: P retention of some major soils after equilibration with 20 mg/ml P

Soil series	Avail-P Bray P 1 (mg P kg^{-1})	Total P (mg P kg^{-1})	Free Al-Oxide (g kg^{-1})	Free Fe-Oxide (g kg^{-1})	Some results after equilibration	
					P remaining in solution (mg g^{-1})	Fe-P (mg g^{-1})
Kumayili (Chromic Lixisol)	4.3 (6.3)	91	0.123	0.45-0.63	11.4	1.92
Kpelesawgu (Eutric Plinthosol)	4.4 (6.3)	82	0.123	0.06-0.63	11.7	3.84
Wenchi (Plinthosol)	4.9 (6.2)	280	0.226	0.24-1.88	3.5	29.40
Changnalili (Stagnic Plinthosol)	11.0 (6.1)	103	0.124	0.07-0.58	8.8	12.50

Source: SRI, 1975 Soil pH in parenthesis

Studies on management of acid soils to improve the soil conditions and P availability have been carried out in many parts of the country (Lathwell, 1979; Ofori 1971; Dennis and Issaka, 1986, 1987, 1990; Issaka et al, 2003). According to Ofori (1971), liming at 0.5 or 1.0 t ha^{-1} is sufficient to improve the soil pH and the soil condition for normal plant growth. These findings were supported by Dennis and Issaka (1986, 1987, and 1990) who reported that 0.5tha^{-1} lime was enough to improve soil pH and/or P availability. The authors also observed that the use of organic matter (rotten corn cobs) also improved soil pH and P levels. Soils that require high P input can be managed by initially applying high doses of P to correct the initial deficiency. Maintenance application of 9 to 26kg P ha^{-1} will provide adequate P nutrition for annual food crops (Lathwell, 1979). Lathwell (1979) also observed that liming improved both soil pH and P availability at Kwadaso in the Ashanti region and Aiyinasi in the south-western part of Western Region. According to him at Kumasi and Aiyinase effect of applied P was greatest without liming the soil. He stated that the marked reduction in response to applied P due to liming may be due to the mineralization of organic P in these soils as a consequence of the added lime. Mineralization of organic P leads to the improvement of available P in the soil hence the reduction or lack of response to added P.

Application of lime at lower rates of 0.5 and 1.0t ha^{-1} prevents over liming. Most soils in the country are poorly buffered and over liming can be a serious problem. Liming not only improves the soil environment and available P but adds calcium and depending on the source magnesium and micronutrients (Issaka et al, 2003). This addition of some basic cations into the soil through liming is very significant given the low exchangeable cations in most of Ghanaian soils. Use of appropriate crop variety that can tolerate low P status is a possible option. According to Ahenkorah (1997) most of the upland soils are Alfisols, Ultisols and Oxisols and there is therefore the need to manage Al and Mn. According to him, liming and multinutrient application are necessary to ensure good crop yield.

General Outlook and The Way Forward

The review highlights on P status and management in Ghana. P status in most Ghanaian soil is low. The problem is critical because P is easily fixed by sesquioxides and the use of mineral fertilizer in crop production is very low. The absence of P negatively affect yield..

Liming, use of cheap phosphate rock on soils with low pH and application of fertilizers (organic and mineral) are the major practices usually employed to make P available to crops.

Further research in the following areas is necessary.

- Current studies should focus on P management under different farming systems. Rotation or mixed cropping may require P to be managed in a certain way for maximum returns.
- Characterization of soils with respect to their P requirements will provide useful basis for further studies.
- The role of fast growing leguminous cover crops for efficient recycling of P

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Chapter 11

Promotion de l'utilisation des phosphates locaux pour la recapitalisation de la fertilité des sols au Sahel: Etat des lieux des connaissances sur la valorisation agronomique des phosphates naturels du Burkina Faso

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Résumé

La carence quasi générale des sols tropicaux en phosphore constitue l'un des principaux facteurs limitant la production en Afrique sub-saharienne. Les différents travaux sur les phospahtes au Burkina Faso s'inscrivent dans le cadre de l'utilisation des phosphate naturels pour la recapitalisation des terres et l'accroissement durable des productions agricoles. Ces travaux de recherche sur les phosphates naturels du Burkina (Burkina Phosphate ou BP) partent de son utilisation brute à celle de formes plus ou moins solubles. Les principaux résultats on permis de : (i) de définir les doses de BP brute à recommander par culture qui sont de 400 $kg.ha^{-1}$ en fumure de fond et 100 kg ha^{-1} an^{-1} les années d'après ou de 200 kg ha^{-1} an^{-1}, pour le sorgho, le mil, le maïs, le coton, l' arachide et le soja ; de 500 kg ha^{-1} en fumure de fond et 200 kg ha^{-1} an^{-1} les années suivantes pour le riz pluvial; 600 kg ha^{-1} en fumure de fond et 300 kg ha^{-1} an^{-1} les années suivantes pour le riz irrigué, (ii) de mettre au point une formule à base de BP partiellement solubilisé (Bpa) pratiquement équivalente au TSP en terme de production de céréales et meilleur en terme d'éléments P_2O_5, K_2O et CaO sur le sol et est économiquement rentable. Cette formule est : 4,22 N - 24,55 P_2O_5 - 6,26 S - 25,52 CaO - 0,16 MgO. Ce Bpa est ; (iii) la mise au point des techniques de solubilisation biologique du BP par la matière organique lors du compostage aérobie des résidus par adjonction du BP dans les substrats en début de compostage à raison de 80 Kg BP/tonne de substrats organique, par apport direct dans les champs avec le fumier. Des travaux de recherche en milieu paysan portant sur les combinaisons PN et P soluble sur le sorgho ont permis de retenir la formule de combinaison de 75% BP à 25% TSP (P soluble) ou de 50% BP + 50% TSP associées à un système de production incluant les rotations avec une légumineuse comme le niébé. En conclusion, le BP brute est efficace, (i) dans la lutte contre la dégradation des sols et la récupération des terres dégradées, (ii) dans l'amélioration de la nutrition des plantes par l'amélioration des propriétés physiques, chimiques et biologiques des sols, (iii) dans la stabilisation des rendements pour une agriculture durable. Cette efficacité du BP brute s'exprime dans des conditions agro-pédo-climatiques favorables à l'amélioration de sa solubilité (sols acides de pH inférieur à 6.5, faible pouvoir fixateur, forte carences en phosphore, bonne capacité d'échanges cationiques, bon taux de matière organique et dans une zone dont la pluviométrie annuelle est comprise entre 500 mm et 1300 mm / an).

Mots clés: *sols tropicaux, phosphates naturels du Burkina Faso, doses, formule, techniques de solubilisation, zones agro-pédo-climatiques*

Abstract

The almost general deficiency of the tropical soils in phosphorus constitutes one of the main factors limiting the production in sub-Saharan Africa. The present work is to make a knowledgments on the use of Burkina Rock phosphate in the recapitalization of there soils fertility in order to increase agricultural production. Many research was done in this way and the main results permitted to: (i) define the doses of rock phosphate to recommend by culture that is of 400 kg.ha^{-1} in bottom dose and 100 kg ha^{-1} $year^{-1}$ the years after or of 200 kg ha^{-1} every year, for sorghum, corn, cotton, peanut and the soybean; of 500 kg ha^{-1} in bottom rate and 200 kg ha^{-1} $year^{-1}$ the following years for the pluvial rice; of 600 kg ha^{-1} in bottom rate and 300 kg ha^{-1} $year^{-1}$ the following years for the irrigated rice. (ii) finalize a formula basis on partially solubilised rock phosphate whose is: 4.22 N - 24.55 P_2O_5 - 6.26 S - 25.52 CaO - 0.16 MgO. This one is practically equivalent to TSP in term of production of cereals and better in term of P_2O_5 elements, K_2O and CaO on soil and, is economically profitable. (iii) clarified the biological solubilization techniques of the rock phosphate by the organic matter during composting of the residues if it was add in at the beginning of composting in the rate of 80 Kg per tonne of organic residues. Results of research in peasant environment carrying on the rock phosphate combined with soluble phosphorus on sorghum permitted to increased production with the formula combining 75% rock phosphate to 25% TSP or 50% rock phosphate + 50% TSP associated to the rotation with cowpea. In conclusion the rock phosphate is efficient, (i) in the struggle against the soils degradation and the recuperation of the degradated soils, (ii) in the stabilization of the productions for a lasting agriculture. This efficiency expresses itself in specifics agro-pedo-climatic conditions favourable to the improvement of his solubility. (annual rainfall between 500 to 1300 mm, pH about 6.5, good CEC, good level of organic matter, deficiency on P).

Key words: *Tropical soils, Burkina Faso phosphate rock, rate, formululation, PR technique of solubilization*

Introduction

Pour l'alimentation des cultures, les nutriments utiles sont classés en deux groupes à savoir (1) les éléments majeurs et (2) les éléments mineurs ou oligo-éléments

L'azote (N), le phosphore (P) et le potassium (K) sont considérés comme éléments majeurs à cause de leur importance quantitative et qualitative pour la nutrition végétale. Le Phosphore (P), constituant essentiel des molécules de transport de l'énergie (ATP) et de l'information (ADN) dans les organismes vivants, est l'un des éléments majeurs de la nutrition des plantes. En plus de ce rôle important, le P est considéré, après l'azote, comme l'élément nutritif le plus limitant des rendements agricoles dans la plupart des sols tropicaux d'Afrique. En effet dans les pays sahéliens de l'Afrique de l'Ouest, le phosphore est l'élément nutritif qui limite les réponses de plusieurs cultures lorsque l'humidité du sol permet d'assurer une alimentation hydrique satisfaisante de ces cultures (Bationo Et Mokwunye, 1991). Les teneurs en P total dans les sols non cultivés sont faibles et généralement inférieures à 200 mg kg^{-1}. Il en est de même des teneurs en P bio disponible dans ces sols (Compaore et al., 2003). Les teneurs en P assimilable (Bray 1) sont en moyenne comprises entre 1,7 et 5,6 mg kg^{-1}. Celles du Phosphore isotopiquement échangeable en 1mn (E_{1mn}) et échangeable entre 1mn et 1 jour (E_{1mn-1j}) sont respectivement de 0, 16 mg kg^{-1} et de 0,66 mg kg^{-1}. Enfin le phosphore disponible entre 1jour et 3 mois ($E_{1j-3\ mois}$), c'est-à-dire durant la période de culture, n'est que de 1,34 mg kg^{-1}. Cette déficience prononcée en P des sols des régions arides et semi-arides s'explique par : (i) la pauvreté de leurs matériaux originaux en minéraux de réserve, (ii) leur pauvreté en minéraux capables de fournir du P inorganique au cours du temps, et (iii) leurs faibles teneurs en P organique, conséquences de leurs faibles teneurs en matières organiques (les matières organiques d'une part contribuent pour au moins 50% au pool de P assimilable des sols à faible pouvoir fixateur et d'autre part réduisent la rétrogradation du P dans les sols à fort pouvoir fixateur). La faible biodisponibilité du phosphore de ces sols dépend aussi de facteurs tels que (i) la faible activité et la surface spécifique réduite des argiles dominantes constituées par la kaolinite, (ii) leurs teneurs le plus souvent élevées en oxydes de fer et d'aluminium, (iii) leur faible Capacité d'Echange Cationique (CEC), (iv) leur faible teneur en matières organiques (MO) et, (v) leur pH acide (Nwoke et al., 2003 ; Kwabiah et al., 2003). Les modes de gestion de la fertilité des sols et le type de culture ainsi que le régime pluviométrique, jouent également un rôle dans l'alimentation en P des plantes (Bationo Et Mokwunye, 1991). Or la plupart des modes de gestion de la fertilité des sols et l'environnement socio économique en Afrique ne permettent pas aux activités agricoles d'assurer de façon durable l'augmentation des rendements nécessaire à la satisfaction des besoins alimentaires d'une population en permanente croissance (Thiombiano et al., 1996 ; Marjatta., 2006). Le faible niveau de fertilité naturelle des sols lié à l'ancienneté de leur pédogenèse, l'adversité du climat (la majorité des climats est aride à semi-aride), l'inadaptation des systèmes de production (pratiques culturales traditionnelles le plus souvent de type minier), l'inadéquation des politiques de promotion de l'investissement dans le secteur agricole sont entre autres des contraintes au développement de l'agriculture en Afrique (Bationo et al., 2006). Dupont de Dinechin et Dumont (1967) ont même montré que la carence en P se retrouvait dans les zones à forte pression foncière.

Le Burkina Faso à l'instar des pays sahéliens dispose d'importants gisements de phosphates naturels dans sa région Est. Ces phosphates du Burkina (BP) ont fait l'objet d'études antérieures dans le sens de leur meilleure valorisation dans les productions agricoles à travers toutes les zones agro écologiques du pays. .Le présent chapitre est une synthèse des principaux résultats obtenus par les chercheurs afin de mieux faire connaître les performances de ce produit pour la recapitalisation en P des sols qui du reste sont pour la plupart carencés en cet élément.

Rôle du phosphate naturel dans la gestion de la fertilité des sols

Selon les résultats d'expérimentations de recherches agro-pédologiques synthétisés par Bumb et al. (1996), Lompo (1995) et Kouma (2000), le phosphate naturel tout comme les autres sources de P, joue plusieurs rôles dans la gestion de la fertilité des sols.

Les phosphates naturels comme sources de reconstitution du P des sols.

La recapitalisation du P des sols peut se faire au moyen de l'application de n'importe qu'elle type d'engrais phosphaté (TSP, SSP, phosphates naturels et autres…). Toutefois, les Phosphates naturels ont des avantages bien spécifiques. En effet partant des phosphates naturels du Burkina (Burkina Phosphate ou BP) on peut relever:

(1) le Burkina Faso dispose de grandes quantités de Phosphate naturel dans ses réserves de Kodjari et d'Arly sis à l'EST. L'utilisation de cette ressource locale est non seulement économique pour la région, mais est aussi source de création d'emploi pour les populations locales;

(2) le Phosphate naturel de Kodjari (Burkina phosphate) qui est celui exploité en ce moment, est très peu soluble dans l'eau, donc libère progressivement le P une fois appliqué au sol. En effet des études ont montré que le Burkina Phosphate libérait seulement une infime partie de son P pendant la 1ère année de son application. Cet état de fait permet alors au sol d'absorber le reste de P du phosphate naturel (la plus grande partie) pour reconstituer ses réserves en P. Ceci justifie l'application des doses de fonds en Burkina Phosphate qui vont, non seulement améliorer le capital en P des sols, mais réduiront simultanément les quantités de sources complémentaires de P solubles nécessaires pour reconstituer le P agricole

(3) le Burkina phosphate contient du Calcium ainsi que d'autres oligo-éléments. Son application peut alors permettre, la satisfaction des besoins des plantes en ces oligo-éléments et l'amélioration du pH des sols acides.

Le Phosphate naturel dans la prévention de la dégradation des sols

L'historique de l'évolution des terres au Burkina Faso, montre qu'à l'origine les exploitants avaient des sols d'une bonne fertilité. Au fil des années, ils ont assisté à une baisse de cette fertilité qu'ils ont attribué en partie aux conditions climatiques devenues de plus en plus rudes pour la nature (baisse de la pluviométrie, disparition du couvert végétal, etc.) (Lompo et al., 2000). Aussi, dans les régions fertiles de l'Ouest Burkina, ce fût la surexploitation des terres avec les cultures de rente telles le cotonnier, l'arachide et le sésame pour les besoins des industries coloniales (de France), qui a appauvrit les sols. En ce moment le même comportement semble s'installer dans la région de l'EST avec la relance de la production cotonnière et certainement d'autres cultures de rente.

Pour lutter contre cette baisse de la fertilité, les exploitants assez riches de l'Ouest utilisaient les engrais minéraux. Ceux du reste du pays, moins nantis, ont fini par « vider » le sol de ses réserves en nutriments par la pratique de l'agriculture minière, la jachère étant devenue pratiquement impossible.

Dans la zone Est et partout ailleurs, il est possible de restaurer les terres dégradées et abandonnées à un coût qui soit de loin beaucoup moins élevé que celui nécessaire à la défriche de forêts secondaires à des fins agricoles. Pour cela, il faudrait une application du Phosphate naturel (Burkina phosphate) en dose de fond associé à des légumineuses à croissance rapide et fixatrices d'azote atmosphérique, comme plantes de couverture. Ainsi une bonne production agricole est possible sur ces sols en prenant soin d'appliquer les techniques culturales adaptées avec des apports annuels d'engrais minéraux en fumure d'entretien (Bumb et al., 1996).

Le Phosphate naturel dans l'amélioration des propriétés physiques, chimiques et biologiques des sols

Il est ressorti de nombreux travaux que le Phosphate naturel améliore les propriétés physiques, chimiques et biologiques des sols en (Hien, 1992; Kambire, 1994; Lompo et al., 1994; Sedogo et al., 2001):

(1) améliorant la structure des sols lorsqu'il est combiné au fumier;

(2) stabilisant la production des céréales lorsqu'il est apporté en fumure de fond associé au fumier, avec amélioration du niveau de P total, du Ca et du magnésium des sols (tableau 1). Le tableau 1 indique que le P total est plus élevé pour les doses annuelles de BP (BP annuel et BP annuel plus fumier) mais le P assimilable (P ass..) est plus important pour le BP annuel + fumier. Les teneurs en calcium et en magnésium augmentent avec les traitements ayant reçus le BP

(3) stimulant l'activité et la prolifération des souches microbiennes favorables à la décomposition des substrats organiques, à travers l'utilisation des phospho-composts comme le montre Bado (1985). L'appréciation de la vitesse de décomposition des substrats organiques (Litière et Paille) (tableau 2) est faite à partir des pourcentages de pertes en matière sèche qui sont les reflets de l'activité biologique régnante dans le phosphocompost. Ils sont plus importants lorsqu'on apporte le BP, preuve d'une activité biologique intense induite par la présence du BP

Tableau 1: Effet des apports de phosphate naturel du Burkina avec le fumier sur les caractéristiques chimiques du sol à Saria, Burkina Faso (1991)

Traitements	pH Eau	C tot. (%)	N tot. (%)	P tot. (ppm)	Pass. (ppm)	Ca (me/100 g)	Mg (me/100 g)
Témoin absolu	4.5	1.17	0.42	197	1.42	1.67	0.34
NPK vulgarisé	4.2	0.21	0.20	198	3.40	1.29	0.23
BP annuel	5.0	0.21	0.19	252	4.78	2.15	0.34
BP annuel + fumier	4.8	0.28	0.17	241	6.79	2.42	0.38
BP correction + BP annuel	5.0	0.20	0.14	215	5.71	2.16	0.38
BP correction + BP annuel + fumier	5.2	0.25	0.09	222	6.30	2.16	0.31
Sol départ (1982)	5.5	0.82	0.21	-	-	1.70	0.68

Source : Lompo et al. (1994)

Tableau 2: Effets de l'adjonction des phosphates naturels du Burkina sur les pertes de matières sèches après six (06) mois de compostage aérobie à Saria, Burkina Faso

	Quantité de départ (kg m.s)	Quantité au bout de 6 mois (kg)	Pertes (%)	pH eau
Paille	60.0	51.0	15	8.2
Paille + BP	62.4	49.9	20	6.9
Paille + Urée + BP	62.4	47.0	25	8.2
Litière	60.0	41.4	31	8.2
Litière + BP	62.4	42.4	32	8.5
Litière + Urée	60.0	36.0	40	7.4
Litière + Urée + BP	62.4	31.1	50	6.8

Source: Bado (1985).

Les pourcentages de pertes en matière sèche sont plus importants lorsqu'on apporte le BP, preuve d'une activité biologique intense induite.

Interaction du phosphore avec les autres éléments nutritifs

Le phosphore, lorsqu'il est appliqué dans le sol, subit une certaine dynamique. On assiste d'abord à une dissolution plus ou moins rapide de l'engrais phosphaté dans le sol, puis l'ion phosphore subit sous l'action des constituants du sol les réactions suivantes:

- absorption dans la réaction avec les oxydes de fer et d'aluminium
- précipitation et transformation de l'ion P en des formes de plus en plus stables ;
- absorption de l'ion P par des composés organiques.

Toutes ces réactions varient en fonction de la qualité des sols : acides ou neutre, teneur en matière organique et en bases échangeables etc.

Par rapport aux autres éléments nutritifs, des travaux ont montré que le P favorisait leur absorption par les cultures. C'est ainsi que Bationo (1979) indique à travers les travaux de Roberson et al. (1954), Cole et. al. (1963) que l'interaction phosphore-azote augmentait significativement l'absorption du phosphore du SSP mais cela nécessitait un mélange intime de la source de N avec celle de P. Ceci explique en partie l'intérêt de l'utilisation des engrais mixtes (ayant plusieurs éléments nutritifs).On notera que cette interaction reste positive pour les autres nutriments, notamment les oligo-éléments. Au regard de l'importance des interactions entre le P et les autres nutriments, par rapport à l'alimentation végétale, on peut comprendre pourquoi on porte une attention particulière sur la correction de la carence de nos sols en cet élément. Ainsi, le phosphate naturel du Burkina, dans sa dissolution progressivement assurera dans les sols, la présence continue de cet élément capital. Des travaux ont d'ailleurs montré que cette solubilisation progressive favorisait un effet dit « résiduel » du phosphate naturel pendant une période plus ou moins longue. Roch et Pichot (1985) de même que Visker et al. (1994), Bumb et al.(1996), ont d'ailleurs conclu que quelque soit la dose de phosphate naturel appliquée, il se produit un effet résiduel qui s'étendrait jusqu'à la septième voir la neuvième année de culture et que la réponse des cultures à l'application initiale de même qu'au phosphate résiduel, augmentait avec les doses plus élevées. Ceci montre une fois de plus la nécessité de l'utilisation du Burkina phosphate et d'autres phosphates naturels comme amendements pour les sols notamment celles du Burkina Faso.

Conclusions

Au vu de ces résultats, le PN ainsi que d'autres sources de P comme les engrais minéraux phosphatés, le fumier et d'autres matières organiques, les phospho-composts, permettent d'améliorer les quantités en P du sol et résolvent ainsi le problème de carence généralisée en P des sols du Burkina Faso.

Le PN présente des intérêts particuliers pour le Burkina Faso:

- baisse des investissements en importation des phosphates solubles;
- création d'emplois pour les populations locales de Kodjari à l'est;
- recapitalisation des réserves en P des sols;

- apports significatifs d'oligo-éléments dans les sols (Calcium et magnésium) et réduction de l'acidité des sols;
- restauration des terres dégradées et récupération des terres abandonnées en associant le BP à d'autres techniques culturales appropriées;
- amélioration des propriétés physiques, chimiques et biologiques des sols.

En somme, le Burkina Phosphate est un amendement intéressant pour l'amélioration du niveau de fertilité des sols dégradés et pour la recapitalisation en P des terres non encore dégradées afin de faciliter la réponse des cultures aux apports extérieurs d'éléments nutritifs.

Au regard des concepts de base sur le phosphore, toute bonne action d'utilisation d'une source de P devrait pouvoir améliorer le P capital, stock en P du sol, et/ou le P agricole qui est celui disponible pour les cultures en fonction des objectifs visés.

Pour agir sur ces deux concepts, deux possibilités sont offertes:

(1) l'utilisation d'engrais minéraux phosphatés. Ces engrais de part leur nature, soluble, agissant plus sur le P agricole, mettra immédiatement le P à la disposition des cultures. Une partie du P non absorbé restera alors au niveau du P capital;
(2) l'utilisation d'un amendement, en l'occurrence le BP ou tout autre phosphate naturel.

En effet, le BP, de part sa nature très peu soluble, libèrera progressivement 25 à 27% P_2O_5 dans les sols, enrichissant ainsi le P capital et le P agricole. C'est pourquoi on le recommande comme amendement pour la recapitalisation du P des sols du Burkina Faso. La présence de certains oligo-éléments comme le calcium et le magnésium reste un atout supplémentaire à son adoption comme amendement. Aussi la présence permanente du P après son application favorise les interactions bénéfiques avec les autres nutriments, nécessaires à leur meilleure absorption par les cultures.

Les questions suivantes restent alors à éclaircir:

(1) de quoi disposons-nous comme phosphate naturel: qualité, quantités, coûts et quelles sont les politiques actuelles de l'État en matière d'augmentation des productions et d'amélioration des circuits de distribution?
(2) comment promouvoir l'utilisation du BP à travers le pays, partant des résultats de recherche déjà existante en la matière?

Les sections suivantes traiteront ces deux questions.

Etat des lieux sur la valorisation agronomique des phosphates naturels du Burkina (BP)

Dans tous les travaux de recherche, les phosphates naturels du Burkina (BP) sont présentés comme des phosphates tricalciques très peu solubles à l'eau. Certains auteurs les classent même parmi les « moins bonnes » du point de vue solubilisation dans la sous région ouest africaine. En effet les résultats d'analyse de plusieurs phosphates naturels contenu dans le tableau 3 le témoignent.

Tableau 3: Comparaison de plusieurs phosphates naturels en fonction de leur teneurs en phosphore, en calcium et du taux de solubilité

	Phosphore total % (1)	Calcium total % (1)	Solubilité du P (2)	Silice % (3)
Burkina Faso				
Arly	13,4	34,0	49,29	10,03
Kodjari	13,1	32,0	48,48	6,21
Sénégal				
Matan	12,8	35,5	-	4,52
Taiba	15,9	32,0	41,54	2,24
Niger				3,31
Tahoua	15,0	32,0	36,10	
Mali				
Tilemsi	12,2	30,8	61,21	3,64
Togo				
Kpeme	15,4	26,0	40,93	0,55
Tunisie				
Gasfa (4)	13,2	22,8	91,58	1,60

(1) la teneur équivalente en P_2O_5 est obtenu en multipliant la teneur en phosphore total par 2.291 et celle du Ca0 en multipliant la teneur en calcium total par 1.4.

(2) solubilité exprimée en % de phosphore total dans l'acide formique à 2 %.

(3) teneur en silicium principalement lié au quartz.

(4) phosphate de référence de très bonne qualité.

Source: Bulletin UGFS, Agri. Dur., vol. 4 et 5, 1999.

Au regard de ces données, le BP s'avère effectivement d'assez faible solubilité ($\simeq$ 50 % du P total) dans l'acide formique soluble. Ce taux lorsqu'on le ramène à l'eau devient très faible ; en effet, selon Lompo (1994) le taux de dissolution du BP dans l'eau serait d'environ 0,03 %. Pour augmenter la solubilité du BP, les premiers travaux ont essentiellement porté sur la réduction de la taille des granules, le BP à l'état naturel étant en bloc de roche. Ainsi on est passé des granules de 1.18 et 3.35 mm de diamètre à de la poudre dont les mini-granules ont une taille comprise entre 90 et 112 µm (Roy et Mcclellan, 1986). Le broyage du BP améliore certes sa solubilité mais ceci reste très faible quant on sait que le ratio molaire PO_4/CO_3, indicateur principal de réactivité du phosphate est d'environ 23.0, celui des phosphates naturels, les plus réactives devant être inférieur à 5 (Mokwunye, 1994). De ce fait il est justifiable de poursuivre les travaux visant à améliorer la solubilité de notre phosphate naturel.

Pour ce faire des travaux ont été effectivement conduits dans ce sens se basant surtout sur les conditions de solubilisation plus ou moins naturelles.

Identification des conditions agro-pedo-climatiques favorables à la solubilisation des BP pour une optimisation de son efficacité agronomique.

Conditions pédologiques

Le Burkina Faso, compte plusieurs types de sols représentés par les groupes suivants (Lompo, 1995) :

(1)	les sols ferrugineux tropicaux	39,1 % des sols du Burkina Faso ;	
(2)	les sols peu évolués	26,2 % “	‘’
(3)	les sols hydromorphes	12,8 % ‘’	‘’
(4)	les sols bruns eutrophes	6,2 % ‘’	‘’
(5)	les vertisols	5,8 % ‘’	‘’
(6)	les sols halomorphes	4,8 % ‘’	‘’
(7)	les sols minéraux brutes	3,2 % ‘’	‘’
(8)	les sols ferralitiques	1,9 % ‘’	‘’

On notera que la majeure partie des terres agricoles se situe dans les groupes des sols ferrugineux tropicaux, des sols hydromorphes (notamment dans les bas-fonds et les périmètres irrigués), des sols ferralitiques et dans une moindre mesure les sols peu évolués et des vertisols (principalement dans les zones aménagés dites AVV, précédemment siège de l’Onchocercose). Ces sols de part leur nature réagissent différemment vis-à-vis des apports de BP. Leurs réactions sont généralement fonction de certains de leurs propriétés chimiques, physiques et biologiques. Des chercheurs se sont également intéressés à cette question. La synthèse suivante fait le point des résultats de leurs travaux.

Importance du niveau d’acidité des sols sur la solubilisation de phosphates naturels

L’alimentation phosphorée du végétal est assurée par les formes ioniques HPO_4^{2-} $H_2PO_4^-$ présentes dans la phase liquide du sol (Morel, 1996). Leur présence dans la solution du sol est rendu possible suite à une conversion des ions PO_4^{3-} en présence d’ions H^+ (Khasawneh et Doll, 1994 ; Truong et Fayard, 1994 ; Kouma, 2000). De ce fait, la capacité du sol à fournir des ions H^+ reste la condition majeure à l’efficacité du phosphate naturel. Ainsi, les phosphates naturels ne peuvent enrichir la phase liquide du sol en phosphore que si le pH du sol est inférieur à 6,5. Leur emploi dans des sols de pH supérieur à cette valeur n’est pas à recommander, et en particulier dans les sols calcaires (Morel, 1996).

Importance du pouvoir fixateur des sols sur la solubilisation des phosphates naturels.

Le pouvoir fixateur du sol est déterminé par la quantité F de phosphate soluble nécessaire pour porter jusqu'à un niveau standard la concentration d'équilibre de la phase liquide du sol dont le niveau de référence habituel est de 3 mglitre^{-1} selon les travaux de Gachon (1966 et 1969; Morel, 1996).

L'importance du pouvoir fixateur dans la solubilisation des phosphates naturels, (dont le BP) porte sur le fait que plus il est élevé, moins le sol est favorable à la solubilisation, et, moins il est élevé, plus le sol est favorable à la solubilisation du BP.

Selon Morel (1996) deux facteurs influencent principalement le pouvoir fixateur du sol:

(1) la teneur en argile : la teneur en argile augmente le pouvoir fixateur, donc est moins favorable à la solubilisation du Burkina phosphate;

(2) la présence de substances organiques (taux de M0) diminue le pouvoir fixateur, se révèle ainsi bénéfique quant à la mobilisation du phosphore du sol. En effet, la décomposition de ces substances organiques s'accompagne d'une production de gaz carbonique. Ce gaz une fois dissous dans la solution du sol produit de l'acide carbonique capable de décomposer le phosphate brut et de le rendre disponible à la plante.

Conclusion

La qualité du sol doit convenir à l'apport afin de faciliter la solubilisation du Burkina phosphate. Les meilleurs sols doivent avoir les caractéristiques suivantes :

- faible acidité: pH <6,5;
- faible pouvoir fixateur, donc faible taux d'argile;
- forte carence en P;
- bonne capacité d'échange cationique (CEC);
- bonne rétention en eau;
- bon taux de matière organique du sol.

Conditions agronomiques favorables à la solubilisation du Burkina phosphate

Les conditions agronomiques favorables à la solubilisation du Burkina phosphate ont fait l'objet de plusieurs travaux. On remarquera que la plupart des auteurs les ont appréciés à partir des résultats sur la production agronomique. Certains auteurs expliquent les résultats obtenus à partir des facteurs dont:

(1) le type de sol dont les qualités sont énumérées au point ci-dessus;

(2) le mode d'apport du Burkina phosphate : pour Bikienga, (1980) l'amélioration de l'efficience de la fertilisation phosphatée avec le phosphate naturel, passe par un épandage tel que la surface de contact entre le sol et le phosphate naturel soit la plus grande possible. En effet, la mobilité du P étant faible, la source de P doit être placée dans le sol de façon à rapprocher le maximum possible le P de la plante. Pour cela on recommande l'épandage à la volée suivi d'un labour d'incorporation;

(3) le temps de réaction du Burkina phosphate : ceci est un facteur important car la dissolution du phosphate naturel est un processus qui s'étend sur un temps plus ou moins long, ce qui donne une haute valeur résiduelle à ce produit. Cette période de réaction peut être couverte par des apports en P d'autres sources plus solubles et ceci en fonction de la culture à mettre en place.

Pour une meilleure appréciation de l'ensemble de ces facteurs agronomiques quant à l'efficacité du BP, les productions obtenues avec les essais et tests multi locaux sont d'un grand intérêt. En effet, beaucoup d'essais multi locaux et pluriannuels ont été menés entre 1976 et 1992 dans lesquels le BP a été mis en comparaison avec les autres sources de phosphore utilisé au Burkina Faso (TSP, SSP, DAP).

Effets du Burkina Phosphate sur la production du riz au Burkina Faso

En matière de production de riz des essais et tests ont été conduits aussi bien sur la riziculture irriguée que sur la riziculture pluviale.

- Effets en riziculture irriguée

  Les essais de Hien et al. (1992), dans le périmètre irrigué de la Vallée du Kou dans le Sud-Ouest du Burkina, mettaient en comparaison le BP avec le TSP (phosphate super-triple) pendant trois (03) campagnes. Une synthèse des résultats donne le tableau ci-dessous.

Tableau 4: Rendements (kg ha^{-1}) de riz paddy – Vallée du Kou, Burkina Faso

	Burkina phosphate (BP)			Phosphate super triple (TSP)		
P_2O_5 (Kg ha^{-1})	SH88	SS88	SH89	SH88	SS89	SH89
0	4975	944	1020	4975	994	1020
30	5122	1216	1023	4634	1726	1676
60	5131	1461	1214	4979	1390	1389
90	4807	1817	1133	4556	1707	1268

Source : Hien et al. (1992), SH = saison humide, SS = saison sèche

Le coefficient d'efficacité relatif du BP par rapport au TSP sur le riz irrigué donne le tableau suivant:

Tableau 5: Coefficient d’efficacité relatif du phosphate sur le riz irrigué dans la Vallée du Kou au Burkina Faso

P_2O_5 ($Kg\ ha^{-1}$)	Saison humide 1988 BP	Saison sèche 1989 BP	Saison humide 1989 BP	TSP
30	114	7	40	100
60	110	133	78	100
90	124	121	80	100

Source : Hien et al. (1992),

Les rendements en riz paddy, les coefficients d’efficacité relative et les fonctions de production reliant le phosphate et les rendements grains ont permis d’aboutir aux conclusions:

- le BP n’est pas efficace sur le riz irrigué à de faibles doses, moins de 500kg ha^{-1};
- le BP est plus efficace que le TSP lorsqu’il est apporté à des doses élevées.

L’inefficacité des doses faibles de BP en riziculture irriguée serrait liée au type de sol de ces périmètres. En effet, il s’agit des sols hydromorphes, très riches en argiles et en hydroxydes, élevant ainsi son pouvoir fixateur. De ce fait une bonne partie du P soluble serait très rapidement fixée dans le sol et échapperait temporairement ou définitivement à l’alimentation de la plante (Hussain et Kyuma, 1970; Kuo et al 1979, cités par Hien et al., 1992). Ainsi les faibles quantités de P solubles apportées par le BP se trouvent totalement fixées d’où sa non efficacité.

Aux doses élevées, le BP parvient à saturer les sites de fixation et le P insoluble en se solubilisant reste disponible pour le riz. En effet, dans ce milieu hydromorphe, la présence d’ions sulfureux et d’autres hydroxydes et la dissolution continuelle du dioxyde de carbone (gaz carbonique) de l’air dans l’eau créent les conditions favorables à une attaque et à une solubilisation du BP. A cela il faut ajouter le pouvoir dissolvant de l’eau d’irrigation dont parle Kouma (2000).

En somme le BP est plus adapté aux sols hydromorphes acides aux doses de 500 kg ha^{-1} en fumure de fond la première année plus 200 kg ha^{-1} en fumure complémentaire annuelle les autres années, les sources solubles étant exposées à la fixation du P.

- **Effets en riziculture pluviale**

Les essais sur le riz pluvial ont donné des résultats concluants comme l’indique le tableau ci-dessus sur sol ferrallitique faiblement acide.

Tableau 6: Effet des phosphates sur les rendements du riz paddy en sol ferralitiques à Farako-Bâ (kg ha^{-1}) au Burkina Faso

	BP		TSP	
P_2O_5 (kg ha^{-1})	1988	1989	1988	1989
0	2533	1643	2533	1643
30	2735	2269	2799	2065
60	3301	2562	3054	1593
90	3014	2387	3128	2471

Source : Hien et al. (1992),

Les résultats sur l'efficacité relative du Burkina phosphate par rapport au TSP en sol ferrallitique sont mentionnés dans le tableau 7. Les analyses statistiques sur l'évaluation du rapport entre les productions (rendements) et les doses du BP ont montré que le BP est aussi efficace que le TSP dans ces sols. La dose recommandée calculée est de 600 kg ha^{-1}.

Tableau 7: Efficacité relative du BP par rapport au TSP en sol ferrallitique à Farako-Bâ au Burkina Faso

P_2O_5 (kg ha^{-1})	BP		TSP
	1988 (%)	1989 (%)	(%)
30	95,6	124,6	100
60	114,1	137,0	100
90	93,7	78,2	100

Source : Hien et al. (1992),

La réaction «spectaculaire» du BP sur ce sol peut être lié à deux facteurs (1) sa pauvreté prononcée en P rendant le P premier facteur limitant dont la correction stimulerait la production (Hien et al., 1992); (2) l'acidité de sol suffisante pour favoriser la solubilisation du phosphate brute (Chien, 1977 et Truong , 1984).

On pense également que la nutrition phosphatée serait en plus améliorée par la colonisation racinaire importante développée par le riz (à la différence des autres céréales comme le maïs et le sorgho).

En somme, le BP est très efficace en sol ferrallitique acide sur le riz pluvial à une dose optimale de 600 kg BP ha^{-1} en fumure de fond la première année plus 300 kg BP ha^{-1} en fumure annuelle complémentaire, les années suivantes.

Effets du Burkina phosphate sur la production du maïs, du mil, du sorgho, du coton, de l'arachide et du soja

- **Les essais**

Les essais avec l'utilisation du BP comme source de P pour la fertilisation des cultures ci-dessus ont été conduit entre 1976 et 1980, sur sols ferrugineux tropicaux du Centre et du Sud-Ouest du Burkina Faso. Une synthèse des principaux résultats faite par Bikienga Et Sedogo (1983) est présentée dans le tableau 8.

Tableau 8: Bilan des essais sur les phosphatages naturels entre 1976 et 1980 (en kg ha^{-1}) à Saria et Farako-bâ au Burkina Faso

	Saria/Centre				Farako-Bâ/Sud-ouest		
	Coton (76-79)	Sorgho (77-80)	Arachide (76-79)	Mil (77-80)	Coton (76-79)	Maïs (77-80)	Soja (78-79)
Témoin absolu	834	549	1041	673	285	329	480
Témoin NK	906	615	1085	623	360	444	596
NPK vulgarisé	1260	1310	1178	906	732	1748	1338
NPK, P = BP	1155	704	1062	729	377	1073	762
NPK, P = BP (correction)	1253	1138	1162	867	699	1873	1115

Source : Bikienga et Sedogo (1983)

De cette synthèse, Lompo (1995), conclu que l'efficacité des phosphates naturels est d'autant plus prononcée que le pH du sol est acide et que les conditions pluviométriques ou l'humidité du sol restent suffisantes à sa solubilisation. Sur sol ferrugineux tropical dans les régions Centre et Sud ouest on constate que les effets immédiats des phosphates bruts, à la dose comprise entre 25 et 30 $P_2O_5.ha^{-1}$ se situent entre 17 et 70% en sus des rendements du témoin NK.

La formule retenue pour le cotonnier, le maïs et le sorgho sur sol ferrugineux tropical est de: 400 kg BP ha^{-1} en fumure de fond la première année plus 100 kg BP.ha^{-1} en fumure complémentaire annuelle les autres années; ce qui a donné les augmentations de rendements, grains suivants:

+ 600 kg ha^{-1} pour le sorgho

+ 450 kg ha^{-1} pour le coton grain

+ 1500 kg ha^{-1} pour le maïs

De 1981 à 1993, des essais ont été conduits dans la station expérimentale de Gampela pour suivre les arrières effets des phosphatages naturels bruts sur la production du sorgho et ont donnée les résultats suivants:

- dose de 120 P_2O_5/kg: 136 % en 1ère année et 146 % en 2ème année
- dose de 240 P_2O_5: 101% en 1ère année et 210% en 2ème année (Lompo, 1995)

Les mêmes tendances ont été observées sur le mil, l'arachide et le coton.

- **Les tests en milieu paysan**

Après les essais, de nombreux tests avec le BP comme source de P on été faites à travers tout le pays dans le cadre du projet ''Engrais vivriers'', sur les mêmes cultures. Le tableau 9 synthétise les résultats de ces tests.

Pour la conduite de ces tests, le Burkina Faso a été subdivisé en trois (03) zones :

A : pluviométrie annuelle< 600 mm

B : 600 < pluviométrie annuelle< 800 mm

C : pluviométrie > 800 mm

Tableau 9: Synthèse de trois (03) années de tests en milieu paysan dans plusieurs sites à travers le Burkina Faso

	Maïs 50 sites		Mil 52 sites		Sorgho 127 sites	
traitements	Rdt gr. (kg ha^{-1})	Coeff. eff. (%)	Rdt. gr. (kg ha^{-1})	Coeff. eff. (%)	Rdt. gr. (kg ha^{-1})	Coeff. eff. (%)
Témoin abs.	1020	-	542	-	812	-
BP	1759	79	723	55	1095	63
NPK	1973	100	869	100	1260	100

Source : Hien et al. (1992),

Le coefficient d'efficacité agronomique (Coef. eff.) est évalué par rapport au NPK qui est la fumure minérale utilisée.

Les principales conclusions que l'on peut tirer de ces tests en milieu paysan sont les suivantes :

- le BP est efficace sur le maïs dans les zones les plus pluvieuses et sur le mil, plante à forte densité racinaire ;
- sur le sorgho, les réponses à la formule à base de BP est variable selon les zones et pourrait être plutôt fonction du niveau de carence en P du sol et du pH.

Conditions climatiques

De nombreux auteurs ont dans leurs analyses, parlé d'un seul aspect du climat, à savoir la pluviométrie, sauf Chien et al (1980) cité par Kouma (2000), qui a indiqué que la température n'avait pas d'effet significatif sur la dissolution du phosphate naturel.

En effet, comme tous les engrais phosphates, le BP ne peut se dissoudre dans un sol sec. C'est ainsi que Bikienga (1980) indique que pour mieux agir, le BP demande un minimum de pluviométrie, sa solubilisation étant directement liée à l'humidité du sol. Cette humidité du sol autour du minerai, est nécessaire à la fourniture des ions H^+ favorisant la conversion des ions PO_4^{3-} en ions $H_2PO_4^-$ et HPO_4^{2-} essentiels à l'efficacité agronomique du BP (Hammond et al. Cité par Mokwunye, 1994).

Les résultats obtenus dans les tests du projet engrais vivrier (Hien et al., 1992) indiquent que le phosphate naturel est utilisable directement:

- en riziculture irrigué (sol hydromorphes acide avec eau en irrigation)
- en riziculture pluviale et sur le maïs et le mil dans les zones de bonnes pluviométrie (le Sud et le Sud-ouest Burkina).

Aussi, les données recueillis au Burkina par (Hien et al. (1992) indiquent que la réponse des cultures en termes de rendements à l'application des phosphates naturels bruts est linéairement liée à une pluviométrie moyenne annuelle comprise entre 500 et 1300 mm.

Zonage agropédoclimatique pour une utilisation de BP plus efficiente

Un bon zonage des conditions agro-pédo-climatiques favorables à la solubilisation du BP pour une optimisation de son efficacité agronomique doit prendre en compte l'ensemble des conclusions de ce chapitre.

Partant des conditions climatiques, notamment les limites des hauteurs d'eau annuelles (500 à 1300 mm an^{-1}), on pourrait penser que le BP est susceptible d'être soluble dans l'ensemble des zones climatiques du pays sauf la zone sahélienne avec une pluviométrie inférieure à 500 mm an^{-1}. Les zones favorables sont alors les suivantes:

- zone Sub-sahélienne: 500 à 700 mm
- zone Nord sahélienne: 700 à 950 mm
- Zone centre-soudannienne: 950- 1100 mm
- zone sud-oudannienne: 1100 à 1400 mm

En superposant les conditions climatiques à celles agro-pédologiques notamment le type et la qualité des sols (acide, hydromorphes acide, forte carence en P, bonne capacité de rétention en eau et bonne capacité d'échange cationique, faible pouvoir fixateur), les différentes spéculations ayant données de bonnes réponses au BP brute associés à la répartition des principales cultures du Burkina Faso réalisée par Wey (1995), couplée avec le zonage proposé par Lompo (1995), on peut retenir que les zones agricoles suivantes offrent des conditions favorables pour l'utilisation des phosphates naturels.

- les zones irrigables dont le potentiel est estimé à 160.000 ha. Ces zones à prédisposition de culture du riz irrigué principalement sont dispersées à travers le pays. On pense que les plus grandes réserves se situeraient dans le Sud et Sud Ouest (Comoé, Léraba, Poni) notamment dans les bas-fonds et les zones aménagées comme Banzon, Kou, Karfiguela, Niona-Djonkélé, etc.; autour des grands barrages dont la Kompienga, la barrage de Bagré, le barrage du Sourou et certaines petites retenues dispersées dans les provinces.
- les zones aux sols fortement carencés en phosphore accompagnées d'une forte pression foncière. Ce sont les régions du Centre et de l'Ouest du Burkina Faso. On y rencontre les sols ferrugineux tropicaux (centre et ouest) et les sols ferralitiques à l'Ouest. Au centre ce sont les cultures dominantes telles le sorgho, le mil et l'arachide tandis que l'Ouest reste le domaine de la production de maïs, de coton et aussi du sorgho. La surface agricole utile pour ces sols est estimée à 3.765.000 ha.
- Les zones peu peuplées qui sont l'Est et le Sud-Ouest, où la carence en phosphore est moyenne. L'Est du Burkina Faso dont la majorité des sols est de type ferrugineux tropical, est à dominance de mil. Cette culture compte tenu de l'abondance de ces racines donne une bonne réponse au BP brute. L'Ouest du Burkina est une zone dont les sols dominants sont ferrugineux tropicaux (roches acides) et ferrugineux localement, faiblement ferralitique (roches sédimentaires, antécambriennes). On y rencontre une diversification de culture telles le maïs, le coton, l'arachide et même le sorgho. La surface agricole utile (SAU) y est estimée à 4.560.000 ha environs.

Un petit potentiel pourrait exister au Nord dans la province du Soum le long de la frontière avec la République du Mali où on trouve des sols ferrugineux localement faiblement ferralitiques qui peuvent favoriser une bonne solubilisation du BP. Ceci peut-être utile dans les conditions d'une pluviométrie exceptionnelle ou dans des oasis.

Inventaire et évaluation de l'efficacité des recommandations techniques et des pratiques paysannes

Initialement on pensait que les phosphates naturels du Burkina (BP) pouvaient être utilisés comme un engrais. Dès les premiers travaux de recherche, cette hypothèse fut rejetée et le BP de par sa composition minéralogique devait être pris comme un amendement des sols.

Des études telles que développées dans le chapitre précédent, ont permis de :

- déterminer les doses et les réponses des cultures aux apports de BP bruts.
- les techniques chimiques et agronomiques de solubilisation du BP avec la réponse des cultures à ce produit.

Effets des doses recommandées et délais de réponse des apports de BP brut sur les cultures

Des résultats, largement commentés dans les chapitres antérieurs on peut faire les synthèses consignées dans le tableau 10.

Tableau 10: Surplus de production lié à l'apport du BP brute (kg ha^{-1}) site et pays

Doses BP. (kg ha^{-1})	Riz pluvial (1)	Riz irrigué (2)	Sorgho (3)	Mil (3)	Maïs (3)	Coton (3)	Arachide (3)	Soja (3)
400 (fond) + 100 annuel	-	-	600	194	1500	450	121	635
500 (fond) + 200 (annuel)	-	1162	-	-	-	-	-	-
600 (fond) + 300 (annuel)	1092	-	-	-	-	-	-	-

Source : Synthèse faite à partir des résultats de Hien et al (1992)

(1): Surplus moyen de trois campagnes

(2): Surplus moyen de deux campagnes

(3): Surplus moyen de quatre campagnes

En termes de **délais de réponse**, il a été précisé que la réponse optimale des cultures au BP brute était différée d'une campagne ou en d'autre termes l'efficacité optimale du BP était observée la campagne suivant l'apport. Ce délai de réponse a d'ailleurs affaibli l'adoption du BP brut par les agriculteurs burkinabé qui préfèrent une productivité immédiate tout en oubliant l'effet de durabilité (restauration du stock de phosphore des sols).

Parlant de **durabilité de la production agricole**, le Burkina phosphate s'est avéré apte à l'amélioration de certaines propriétés du sol: augmentation du P agricole et du P capital, élévation du niveau de pH des sols acides par les apports de Ca (34% de CaO) et partant de là l'amélioration des conditions de vie microbienne du sol. On notera au passage que ces sols acides sont d'ailleurs utilisés pour la solubilisation du BP qui alors corrigera plus tard l'acidité.

Au vu de tous ces résultats, il est clair que le BP brut est efficace sur les productions aux doses recommandées, mais la réponse différée des apports semble être la cause principale de sa faible ou non adoption par les producteurs. C'est pourquoi la recherche a évolué dans la mise aux points de formules à base de BP partiellement ou totalement solubilisé susceptible d'avoir une réponse immédiate lorsqu'elles sont apportées aux cultures.

Solubilisation partielle chimique du BP (BPA)

La faible solubilité du BP limite son efficacité agronomique lorsqu'il est utilisé directement en fumure annuelle sur des cultures annuelles. L'acidulation partielle, dont le but est d'améliorer la solubilité du BP, consiste à une attaque du BP avec des acides minéraux (H_2SO_4, H_3PO_4, HCl).

Cette attaque est dite partielle car la quantité d'acide utilisée est inférieure à celle requise pour la manufacture des TSP (dans le cas de l'acide sulfurique) SSP (dans le cas de l'acide phosphorique) où l'attaque est totale. On obtient de ce fait un phosphate partiellement solubilisé (PPS, BPA, PAPR)

La formule chimique du BPA (Burkina Phosphate partiellement solubilisé) utilisé est :

4,22 N - 24,55 P_2O_5 - 6,265 - 25,52 CaO - 0,16 MgO (reference).

Des études antérieures ont porté sur les effets du Burkina phosphate partiellement acidulé sur plusieurs types de cultures (Hien et al. 1992).

Les tableaux 11a, b, c, d, e présentent la synthèse de ces travaux :

Tableau 11a: Réponse du riz irrigué et pluvial au BPA à la vallée du Kou, Burkina Faso

	Riz irrigué						Riz pluvial			
	BPA			TSP			BPA		TSP	
Doses (kg ha $^{-1}$)	88 SH	88 SS	89 SH	88 SH	88 SS	89 SH	88	89	88	89
0	4975	944	1020	4975	994	1020	2355	1643	2533	1643
60	5157	1177	1568	4979	1390	1389	3049	2053	3054	1593
90	4493	1660	103	4556	1707	1268	3318	2444	3128	2471

Hien et al. (1992)

Tableau 11b: Coefficient d'efficacité relative du BPA par rapport au TSP à la vallée du Kou Burkina Faso

Doses (kg ha $^{-1}$)	Riz irrigué BPA 88	BPA 89 SS	BPA SH	Riz pluvial BPA 88	BPA 89	TSP
60	112	10	122	99,7	84,2	100
90	94	91	65	110,7	82,2	100

Tableau 11c: Réponse du sorgho, mil et maïs au BPA et coefficient d'efficacité induits par les apports du BPA par rapport au NPK (P = TSP)

	Maïs		Mil		Sorgho	
Traitement	Rdt (kg ha $^{-1}$)	Coef. eff.	Rdt (kg ha $^{-1}$)	Coef. eff.	Rdt (kg ha $^{-1}$)	Coef. eff.
Témoin	1020	-	542	-	812	-
BPA	1716	74	757	66	1153	76
NPK (P = TSP)	1973	100	869	100	1260	100

Hien et al., 1992

Tableau 11d: Réponse du coton et de l'arachide au BPA (kg ha^{-1})

	Coton	Arachide
NK	821	1233
BPA	1059	1591

Kamboule (1984)

Tableau 11e: Bilan minéral : Effet du BPA sur le bilan minéral (extrait de : Etude comparative des sources de phosphore Saria-Centre 1981 - 1991 kg ha^{-1} an^{-1}, (Lompo, 1993)

	Témoin NK 60 N 44 K_2O	NPK (P = BPA) 25 P_2O_5 (ha^{-1} an^{-1})	NPK (P = TSP) 25 P_2O_5 (ha^{-1} an^{-1})
N	- 3	- 19	+ 26
P_2O_5	- 11	+ 10	+ 9
K_2O	+ 13	+ 3	- 0,4
CaO	- 14	+ 6	- 13

Les résultats agronomiques contenus dans les tableaux 11a, b, c, d ci-dessus montrent que parfois les phosphates naturels partiellement acidulés sont pratiquement équivalents aux superphosphates. Les bilans minéraux établis par Lompo (1993) (tableau 11e) indiquent un effet hautement significatif et largement supérieur à celui de TSP pour le P_2O_5, le K_2O et le CaO pouvant satisfaire aux besoins minéraux en P_2O_5 de sorgho et du mil. Le BPA peut être utilisé pour améliorer l'état d'acidité du sol par les apports de CaO et K_2O contrairement au TSP qui donne des bilans négatifs pour ces deux éléments.

Solubilisation partielle du BP par attaque d'oxyde d'azote : Les phosphates humiferts.

Les phosphates humiferts ont été mise au point par la société française de réalisation d'études et conseils (SOFRECO) dans le cadre d'un projet d'études sur les phosphates naturels des pays du Liptako Gourma qui regroupent le Mali, le Niger, et le Burkina Faso.

Les phosphates humiferts sont des phosphates partiellement solubilisés suite à une attaque avec de l'oxyde d'azote ayant comme support les balles de riz. C'est un produit riche en P. soluble (>50 p.c. du P total) à l'eau. Sa teneur en azote, en m.o. et en bases échangeables en fait un engrais NP très intéressant pour les cultures (Lompo, 1993).

Burkina Phosphate ET matière organique : Solubilisation biologique

Solubilisation du BP par la matière organique au cours du compostage aérobie

Le compostage des substrats organiques est un procédé de fermentation biologique. De ce fait on assiste pendant le processus à une élévation de température, un dégagement de CO_2 et la production d'acides organiques. Ces acides de faible concentration vont attaquer le BP adjoint au substrat au cours de compostage et libérer ainsi le P et les autres éléments en son sein. Des travaux de recherche menés à Saria ont permis de donner les quantités de BP a apportées par tonne de substrats à composter pour avoir des effets optimaux sur le BP et les substrats et la période d'apport la mieux indiquée pour cela. Ainsi Bonzi (1989) indique qu'il faut 80 kg de BP par tonne de résidus culturaux à composter et que l'apport en début de compostage donnait les meilleurs rendements.

Solubilisation du BP par la matière organique in situ (au champ)

Les substrats organiques une fois enfouis dans le sol subit les mêmes phénomènes qu'au compostage. En effet, ils sont attaqués par les micro-organismes du sol qui assurent leur décomposition. Cette formation va favoriser la libération du P contenu dans le BP enfoui au même moment que les substrats organiques.

Des travaux antérieurs se sont intéressés aux effets de cette forme de combinaison BP - MO sur le sol et les rendements des cultures annuelles, notamment les céréales traditionnelles (mil, sorgho et maïs). En exemple, les travaux de Lompo (1993) sur le sorgho conduit de 1982 à 1990 donne les résultats du tableau 12.

Tableau 12: Effets du BP + fumier sur les rendements moyens grains de sorgho et sur le sol à saria et à Dédougou

	P total[1] (ppm)	P. ass.[1] (ppm)	Moy. Rendt. Grain[1] (kg ha^{-1} an^{-1} ks)	Rendt. Grains sorgho[2] (kg ha^{-1} DRRA)	Rendt. Grain moy. Milieu paysan[2]
Terrain absolu	197	1,42	407	146	717
BP 200 kg ha^{-1} an^{-1}	252	4,72	693	242	865
BP 200 kg ha^{-1} an^{-1} + fumier (5 t ha^{-1})	241	6,79	887	533	1109
BP 400 kg ha^{-1} 100 ha^{-1} an^{-1}	215	5,71	802	-	-
BP 400 kg ha^{-1} fond + 100 kg ha^{-1} an^{-1} + fumier (5 t ha^{-1} an^{-1})	222	6,30	1034	-	-

Source : [1]Lompo (1993-1994); [2]Kouma (2000)

De ce tableau on souligne une augmentation du P assimilable du sol lorsque le BP est adjoint au fumier dans le sol. Les rendements moyens sont meilleurs pour les traitements BP + fumier aussi bien en station, dans la ferme de la DRRA et en milieu paysan.

Conclusion

Les travaux de recherche vulgarisation sur le Burkina Phosphate ont été pour la plupart concluant. C'est ainsi qu'on pourra énumérer les principales conclusions suivantes:

– Doses de BP brut à recommander par culture:
- sorgho, mil, maïs, coton, arachide, soja: 400 kg.ha^{-1} en fumure de fond et 100 kg ha^{-1} an^{-1} les années d'après
- riz pluvial: 500 kg ha^{-1} en fumure de fond et 200 kg ha^{-1} an^{-1} les années suivantes
- riz irrigué: 600 kg ha^{-1} en fumure de fond et 300 kg ha^{-1} an^{-1} les années suivantes.

N.B.: Délais de réponse du BP brute: un an (différé) pour les cultures pluviales

- Mise au point d'une formule à base de BP partiellement solubilisé dont la composition est :
- 4,22 N - 24,55 P_2O_5 - 6,26 S - 25,52 CaO - 0,16 MgO. Ce BPA est pratiquement équivalente au TSP en terme de production de céréales et meilleur en terme d'éléments P_2O_5, K_2O et CaO sur le sol et est économiquement rentable.
- Mise au point des techniques de solubilisation biologique du BP par la matière organique lors du compostage aérobie des résidus par adjonction du BP dans les substrats en début de compostage à raison de 80 Kg BP/tonne de substrats organique, par apport direct dans les champs avec le fumier.

Conclusions generales, recommandations

Les principales conclusions et recommandations porteront sur 3 points:

(1) Efficacité agronomique du BP brut:

L'efficacité agronomique du BP a été prouvée par de nombreux auteurs. On retiendra alors que le BP brut est efficace,

(1) dans la lutte contre la dégradation des sols et la récupération des terres dégradées,
(2) dans l'amélioration de la nutrition des plantes par l'amélioration des propriétés physiques, chimiques et biologiques des sols,
(3) dans la stabilisation des rendements pour une agriculture durable.

Cette efficacité du BP brut s'exprime dans des conditions agro-pédo-climatiques favorables à l'amélioration de sa solubilité. Ces conditions sont:

- les sols acides de pH inférieur à 6.5, ayant un faible pouvoir fixateur, fortement carencés en phosphore, de bonne capacité d'échanges cationiques, un bon taux de matière organique,
- l'épandage à la volée, suivi d'un enfouissement des doses recommandées par culture qui sont:

riz pluvial: 600 kg ha^{-1} en fumure de fond la 1ère année suivi de 300 kg ha^{-1} an^{-1} les années suivantes,

riz irrigué: 500 kg ha^{-1} en fumure de fond la $1^{ère}$ année suivi de 200 kg ha^{-1} an^{-1} les années suivantes,

sorgho, mil, maïs, coton, arachide, soja : 400 kg ha^{-1} en fumure de fond la 1ère année suivi de 100 kg ha^{-1} an^{-1} les années suivantes,

- être situé dans une zone dont la pluviométrie annuelle serait comprise entre 500 mm et 1300 mm an^{-1}.

Des travaux ont été également réalisés dans le bute d'améliorer la solubilité du Burkina Phosphate et ont abouti aux conclusions suivantes:

- la solubilité du BP est améliorée lorsqu'il est adjoint au compost à raison de 80 kg $tonne^{-1}$ de matière à composter,
- la solubilité du BP est amélioréer in situ lorsqu'il est apporté et enfoui simultanément avec la fumure organique dans les champs,
- la solubilité du BP est améliorée par une attaque à l'oxyde d'azote dans un procédé de phospho-compostage avec les résidus de battage du riz. Ce compostage peut même être industrialisé,
- la formulation de granulés de BP partiellement solubilisé (BPA) par des attaques acides est possible avec la formule de BPA testée.

Recommandation 1

Le BP doit être utilisé comme un amendement pour l'amélioration du niveau de fertilité des sols et la durabilité de la production agricole : élimination de la carence en phosphore et amélioration des propriétés physiques, chimiques et biologiques des sols.

Recommandation 2

Les zones de prédilection pour l'utilisation du BP brute permettant une optimisation de son efficacité agronomique sont :

- les zones irriguables d'environ 160 000 ha repartis dans les bas-fonds, ayant la riziculture comme principale activité,
- les zones du centre et de l'ouest du Burkina Faso aux sols fortement carencés en P et surexploités. Ce sont 3 765 000 ha avec une diversité des cultures comme le sorgho, mil, maïs, arachides, coton,
- les zones peu peuplées à dominance de mil de l'Est Burkina, et le Sud-ouest aux sols faiblement carencés en P avec des cultures comme le maïs, le coton et l'arachide. Le potentiel en surface agricole utile est de 4 560 000 ha.

Recommandation 3

Pour une meilleure solubilisation et une efficacité agronomique non différée du BP il faudra envisager une production industrielle des phosphocomposts ou une transformation du BP en granulés partiellement solubilisés (BPA) dont la formule et la maquette de la micro industrie existent déjà.

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Chapter 12

Cropping systems, land tenure and social diversity in Wenchi, Ghana: implications for soil fertility management

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Abstract

A study was conducted on soil fertility management strategies in Wenchi, Ghana. The original entry point for this study was how to optimize long-term rotational strategies for addressing the problem of soil fertility decline in Wenchi. However, as the study progressed over time, it was realized that what we initially interpreted as soil fertility management strategies were closely intertwined with wider issues such as cropping systems, livelihood aspirations and land tenure relations. Exploration of farmers' soil fertility management practices revealed a link between tenure insecurity among migrant farmers especially, and limited attention for regeneration of soil fertility. The study further revealed that historical, ethnic and gender dimensions of diversity provide additional insights in livelihood patterns and soil fertility management which are relevant for fine-tuning technical and social action research agendas. Farmers' preferences for a particular practice were however more related to accessibility to production resources and livelihood aspiration of the farmer.

Key words: *Cropping systems, land tenure, social diversity, soil fertility management*

Résumé

Une étude a été conduite sur les stratégies de gestion de la fertilité du sols dans le Wenchi au Ghana. Le point de départ de cette étude était comment optimiser les stratégies de rotation de long terme concernant la baisse de fertilité des sols dans le Wenchi. Cependant, au fur et à mesure que l'étude évoluait, il s'est avéré que ce que nous interprétions comme stratégies de gestion de la fertilité des terres était étroitement lié à des aspects plus larges tels que les systèmes de culture, les aspirations de survie des ménages et le droit foncier. L'exploration des pratiques de gestion de la fertilité des sols des paysans a révélé un lien entre l'insécurité foncière spécialement chez les paysans migrants et une préoccupation limitée pour la régénération de la fertilité des sols. L' étude a révélé de plus que les dimensions historiques, ethniques et liées au genre de la diversité, fournissent une compréhension additionnelle des tendances liées à la survie des ménages et à la gestion de la fertilité des sols qui sont pertinent pour l'ajustement de l'agenda de la recherche action technique et sociale. Le choix des paysans est cependant beaucoup plus liées à l'accessibilité aux resources des production et aux aspirations de survie du ménage.

Mots clés: *systèmes de culture, droit foncier, diversité sociale, gestion de la fertilité des sols*

Introduction

In the past, the traditional farming system in Ghana depended on natural soil fertility regeneration through the extended bush fallow system and little on chemical fertilizers (Nye and Stephens, 1962). This system allowed build up of the most limiting nutrients, particularly P and N, in more available forms. However, population pressure and/or the need to increase production have led to a shortening of the fallow periods (Ahn, 1993; Quansah, 1997) resulting in lower crop yields where nutrients are not applied.

Studies in the forest/savanna transitional agro-ecological zone in Wenchi district revealed that farmers, as a response to declining soil fertility levels have developed certain farming strategies to improve or maintain the productivity of their soils (Amanor, 1993; Offei and Sakyi-Dawson, 2002). Notable among these strategies are the inclusion of crops such as cassava (*Manihot esculanta* Crantz), cowpea (*Vigna unguilata* (L.) Walp) and pigeonpea (*Cajanus cajan* (L.) Millsp.) in the cropping system as a form of rotation.

Grain legume rotations have long been recognized as an important practice for maintaining soil fertility because of their N_2 fixing ability (Peoples *et al*., 1995; Giller, 2001; Crews and Peoples, 2004). Cassava cultivation is however assumed to be associated with soil impoverishment (Hendershott *et al*., 1972 cited by Nweke *et al*., 2002; Sitompul *et al*., 1992; Budidarsono *et al*., 1998).

The inclusion of cowpea, pigeonpea and cassava in the cropping systems as a form of rotation by farmers are not only strategies for restoring soil fertility but also strategies for coping with structural conditions and factors such as inaccessibility to resources such as land, labour, inputs and credits as well as food insecurity and risks of crop failure.

We conducted a study in Wenchi, Ghana on soil fertility management strategies among smallholder farmers. This paper reports on how soil fertility management practices were intertwined with wider issues such as cropping systems, land tenure and livelihood ambitions.

Materials and Methods

The study area and population

The study was conducted in three close communities in Wenchi district of Brong-Ahafo region, namely Asuoano (7^o 41' N, 2^o 06' W), Beposo (7^o 41' N, 2^o 07' W) and Droboso (7^o 42' N, 2^o 07' W). Wenchi district has a total population of 166,641 (year 2000 census) of which about 33% is engaged in agriculture. The three communities, all of which lie along the Techiman-Wenchi road, together have a population of about 3750, the majority of which are farmers (Year 2000 census). The communities are made up of two groups of people: the natives, who are mainly Akan speaking Bonos (80%), and migrants (20%). The migrant population consists of four main ethnic groups namely the Walas (50%), the Dagarbas (30%), the Lobis (10%) and the Mossi (10%). Wenchi is strategically located because first, it is relatively close to Wa and Nandom (about 292 and 373 km respectively from Wenchi), which are the original homes of most of the migrants. Secondly, Wenchi is close to Techiman, which is an important marketing centre for the West Africa sub-region and which serves as a market outlet for their farm produce.

The soils in the area which developed on Voltaian sandstones, are mainly lixisols (Asiama et al., 2000). The average annual rainfall is 1271 mm with an average of 107 rainy days. While the total amount of rainfall seems to have decreased slightly over the past 20 years, the total number of rainy days seems to have increased slightly.

Research approach and methods

The study area was selected after an initial exploratory project study revealed the existence of local soil fertility management strategies some of which contradict with dominant scientific beliefs (Offei and Sakyi-Dawson, 2002).

In order to ground the research in the needs of the farming communities, a diagnostic study was carried out in the study area between July 2002 and July, 2003 using Participatory Rural Appraisal tools such as drawing of a community territory map (to identify the differences in soil fertility patterns), a transect walk (to reveal the diversity of the landscape) and analysis of soil fertility management strategies and group discussions. Group discussions (10–40 people) were held in the village centre and/or on farmers' fields. Farmers expressed their ideas by drawing farm maps, pie charts and seasonal calendars and by ranking and scoring.

In addition, two sets of individual interviews each involving about 40 farmers were conducted. The first interview was used to collect qualitative data whereas the second interview was used to collect quantitative data. The individual interviews were semi-structured in nature and served both to get more quantitative data on farm size, household composition and the farming system, and to obtain a better qualitative understanding of the soil fertility management strategies and their underlying rationale.

The diagnostic study was followed by farmer participatory on-farm experimentations with 3 farmer research groups established soon after the diagnostic study to evaluate the agronomic efficacy of the soil fertility management practices being used by the farmers. Six cropping sequences: cassava cropping; pigeonpea cropping; Mucuna/maize/Mucuna rotation; cowpea/maize/cowpea rotation; maize/maize/maize; and *Imperata cylindrica* fallow were evaluated on both farmer-managed and researcher-managed plots. In addition another experiment was set up with the farmers to evaluate the productivity, yields and N_2-fixation in four cowpea varieties and their subsequent residual nitrogen effects on a succeeding maize crop. The cowpea varieties evaluated included three determinate erect cowpeas ('Asontem', 'Ayiyi' and IT810D-1010) and an indeterminate creeping variety (Legon prolific). These resulted in the establishment of an experimental platform through which regular interactions with the intended beneficiaries (i.e. the farmers) and other stakeholders were made possible. This provided an opportunity for taking local knowledge needs into account. More importantly, it allowed farmers' veto to be brought to bear upon the research during the experimentation.

Continuous critical reflections and diagnosis during the collaborative technical experimentation with farmers led to a progressive insight into the complex situation. Consequently, we carried out further exploration of diversity among the farmers to deepen our understanding of soil fertility management. Two hundred and sixty five farmers were selected from the three communities according to ethnicity and gender for interview using semi-structured questionnaires. In addition focus group discussions were held with chiefs, community leaders, family heads and opinion leaders about land tenure systems in Wenchi.

Results

Land tenure arrangements

Four main types of holders of land were identified in Wenchi. These were:

(1) The chief's holding known as the stool land or the traditional land. This is the land the chief holds in trust for the stool. These lands are managed by the "Abusahenes" (literally meaning share cropping chiefs) who are responsible for managing the chief's natural resources, especially land in the traditional area.

(2) Family lands. This refers to the lands that belong to individual families. The family land is usually put under an Abusuapanyin (the head in the line of the inherited siblings) who administers the family land and distributes it among the other siblings with rights in the land.

(3) Individual lands. These are the lands that the first native individual was able to acquire and cultivate. Individual lands are also acquired as gifts from parents.

(4) Government lands. These refer to lands under re-afforestation by the forestry services division of the Forestry Commission of Ghana. These lands are given out to prospective farmers to grow their food crops while planting and maintaining

trees for the commission. This form of arrangement whereby tenant farmers are given land to plant their food crops by the forestry commission while planting and tending trees for the commission is known as *taungya*.

Access to land for farming in Wenchi involves a spectrum ranging from rights acquired through renting to right of use of a piece of land temporarily. Traditionally, ownership of land is based on kinship, but vested in the traditional authority. Among the Akans in Wenchi, a system of family land exists in which having brought a virgin forest land under cultivation yields rights of usufruct 'ownership' as long as the land is kept within a long duration of cultivation. Thus rights could be passed on to the next generation, where it now becomes a family land. Members of the matrilineal family who cleared the land have the right to farm the land. Both men and women in the family have usufruct right in the land. One can also gain access to patrilineal family land. Apart from the chief of Wenchi nobody can sell land to an outsider but land could be rented out or given out for sharecropping for the cultivation of food crops. Since migrants who settle permanently cannot own land in the community, the current land tenure arrangement implies that migrants can only access land for farming through renting, sharecropping or taungya.

Land renting is by far the dominant form of contractual arrangement by which migrants gain access to land in Wenchi. Land can be rented from a family, an individual or stool. For family and individual lands, the land is usually rented for a period of 1-2 years and occasionally 3-5 years, depending on the financial needs of the landowner. When an immediate cash need arises, especially for unexpected emergencies such as funerals, marriages, medical bills, court cases, construction works etc., land is usually rented out beyond 2 years. Rent is paid in advance before the tenant is allowed to cultivate the land. Advance payment is partly due to the fact that landowners prefer to receive the agreed upon rent as soon as possible before it loses its value. Lands are rented out for short periods because of fear of overexploitation of the land by migrants. Currently the cost of renting a hectare of land stands at GH¢50.00 (US$ 55.5). On stool land rent duration is unlimited as long as rent is paid annually. Rent is not paid in advance but at the end of the farming season in the form of farm produce, particularly maize. The annual rent is a 100 kg bag of maize or a cash equivalent. Currently the annual rent is GH¢20.00 (US$21). This rent is also not dependent on size of land cultivated.

There are two forms of sharecropping arrangement depending on the mode of sharing of the crop which in turn depends on the type of crop cultivated. These are the '*abunu*' and the '*abusa*'. These sharecropping arrangements are a characteristic of the forest which originally developed with the expansion of cocoa cultivation (Amanor, 1993). As stated by Amanor (1993:14) on the share-cropping system, '… as many areas of the forest moved over from cocoa production to food crops, these tenure arrangements were extended to food crop cultivation'. Share contracts were introduced into the southern part of Wenchi from *Ashanti* where it is the dominant form of incorporating strangers into the local economy. In Wenchi, the *abusa* system applies to crops like maize which requires high inputs such as labour, mineral fertilisers and herbicides.

The crop is divided into three with two portions going to the tenant farmer while the remaining one portion goes to the landowner. The *abunu* system usually exists for crops such as cassava which has low input demand. In such a situation, the crop is divided into half shares between landowner and tenant. With a crop like yam, which requires a high initial capital outlay for instance for the purchase of seed, no definite mode of sharing of crop is specified. The amount of produce given to the landowner depends on the generosity of the tenant.

Under the taungya arrangement, the Forestry Department of the Forestry Commission allocates part of the land government has earmarked for afforestation to farmers to cultivate their food crops. In return, the tenants are to plant trees and tend them for the commission, and are supposed to leave the land after the trees are established and the canopies of the plantation closed. In reality they do not leave the land, because as strategy to have long term access to using the land, after planting the trees they find a way of killing the trees slowly so that they can stay on the land for a longer period. In the long term by so doing the taungya arrangement can result in transformation of the landscape from forest to grassland (Boserrup, 1965)

Indigenous soil fertility management strategies and their use

Farmers in Wenchi use the following cropping practices for maintaining the productivity of their farmlands: rotations involving cassava; rotations involving legumes such as cowpea, groundnut and pigeonpea; and mounding or ridging.

Crop rotation in general

Farmers believe that different crops feed from different depths and from different nutrients in the soil. Hence they tend to rotate different crops on the same piece of land when they observe yield decline of a particular crop.

Rotation involving cassava

Farmers often crop a piece of land for a period ranging from three to four years to maize and cowpea and when they observe decline in the fertility of the soil, they crop the land to cassava for 18-24 months after which they resume their maize/cowpea rotation. The farmers attribute the role of cassava in soil fertility regeneration to its ability to protect the soil from soil erosion through its canopy and its high leaf litter production, which also shades off the soil from the direct action of the sun and thus increases the activities of soil micro and macro organisms. The farmers attribute these beneficial roles of cassava to the fact that the varieties of cassava that the farmers grow are the spreading types that form a closed canopy and completely shade off the soil within few months after planting. The use of cassava for soil fertility regeneration is not only peculiar to Wenchi. Saidou et al. (2004) also reported on the extensive use of cassava for soil fertility regeneration in some parts of Benin.

Rotation involving pigeonpea

When farmers crop a piece of land to crops like maize, cowpea and yam for about three to four years, they intercrop their food crops with pigeonpea during the last cropping year of the cycle. After harvesting the maize and the yam, farmers allow the land to remain under pigeonpea for 18-24 months after which the pigeonpea plants are cut down, burnt and the land cropped to maize or yam.

From the point of view of the farmers, pigeonpea canopy protects the soil from the direct action of the sun and therefore prevents the soil from becoming hardened. According to the farmers, pigeonpea forms canopy after one year and shades out obnoxious weeds by suppressing their growth. The farmers also explained that leaf litter covers the soil, reduces soil erosion, improves infiltration, prevents heating of the soil and enhances earthworm activity. Crops grown after pigeonpea, especially maize, are perceived by farmers to look greener, grow faster and yield more.

Bush fallows

When farmers observe a decline in fertility of their soils after cropping for three to four successive years, they allow the land to lie fallow for 2-3 years before they go back and crop the land again. According to the farmers, fallowing the land for 2-3 years allows the land to regenerate its fertility. They mentioned that as the land is allowed to fallow, young trees begin to grow and shade the soil so that the land is not exposed to the direct action of the sun thereby keeping the soil moist all the time. They also reason that during the fallow period the litter of the vegetation on the land fertilises the soil as it decomposes.

Rotation with cowpea

Farmers rotate maize with cowpea, which has a growing period of about 60-70 days, because of its food value and marketability and to maintain the fertility of their farmlands. According to the farmers, maize grown after cowpea grows faster and yields higher even if inorganic fertilizer is not applied. They mentioned that the nodules formed on the roots contain energy which is released for the growth of the maize when they decompose. Farmers also attribute the yield increase in maize after cowpea to an increase in fertility of the soil as a result of the decomposition of the cowpea foliage that is left on the land after harvest. However, they remarked that if the land is not immediately used for cropping after harvesting the cowpea the fertility of the land is lost since cowpea foliage decomposes rapidly.

Construction of ridges and mounds

Farmers construct ridges or mounds on less fertile plots on fallowed land On grasslands, farmers either plough the land and/or construct mounds or ridges. Farmers construct mounds or ridges or plough their land for two reasons; firstly, to control problematic weeds that invade the land as a result of decline in fertility and secondly, to improve the productivity of the soil. As they construct the ridges or mounds, the weeds and leaves on the land mix with the soil and fertilize the soil as they decompose. Farmers reason that the decomposed weeds and leaves when mixed with the soil improve the fertility of the soil and increase the yield of maize planted. According to the farmers, the construction of the mounds and ridges also loosens the soil, which becomes compact after continuous cropping. This allows water to percolate into the soil when it rains.

While the natives widely apply bush fallowing and rotation involving long duration crops such as cassava and pigeonpea for maintaining the fertility of their farmlands, migrants who do not own land in the communities but depend largely on sharecropping and land renting for gaining access to land for farming largely use short term strategies such as mounding and rotations involving short duration crops such as cowpea and groundnut.

Table 1. Percentage of native and migrant farmers at Asuoano in 2002, practicing various soil fertility management strategies

Strategy (%)	Native farmers N=22	Migrant farmers N=16
Cassava	82	44
Bush fallow	77	19
Pigeonpea	59	6
Rotation with cowpea/ groundnnut	18	50
Mounding/ridging	14	100

Source: Adjei-Nsiah et al., 2004.

Social diversity and cropping systems in Wenchi

The people of Wenchi are made up of a mixed population of different ethnic groups, the majority of whom are Akan speaking Bonos. Other major ethnic groups include the Mos and the Bandas. In addition large numbers of people have migrated from neighbouring Burkina Faso and the Upper West region of Ghana, most of whom are Mossi, Lobis, Dagarbas and Walas.

In the three communities where the research was carried out, different groups of migrants exist which differ with regard to ethnicity, history and context of migration, duration of stay and the nature and quality of relations with the natives. The earlier groups of migrants (the Mossi and the Lobis who are from Burkina Fasso) and the Dagarbas (who are from the north western part of Ghana) migrated into the area between 1940s and 1960s to work in cocoa farms and later in the state farms. With the decline in cocoa production, the migrant labour force, which hitherto worked on cocoa farms, joined the food crop sector. As a result, more forest land was brought into cultivation which attracted more migrants from the Upper West region into the area. The later group of migrants from the Upper West region who migrated into the area in the 1990s included the Walas. While the earlier groups of migrants (the Mossi, the Lobis and the Dagarbas) have developed long-standing relationships with the natives and regard their stay in Wenchi as permanent, the later group of migrants (the Walas) who migrated into the area in the early 1990s, regard their stay as temporary and have strong ambition to return to their home of origin.

In Wenchi, maize is the most important cash crop in terms of magnitude, followed by yam (which is also a major food crop for the natives). Cassava and cocoyam are the other major food crops besides yam. Other crops of socio-economic importance include pigeonpea, cowpea and groundnut. Cowpea and groundnuts are grown by both natives and migrants while pigeonpea is grown mainly by the natives.

The differences in ambitions with regards to the stay in Wenchi go alongside with differences in cropping systems and soil fertility management practices. The earlier groups of migrants who have developed good relationship with the natives and regard their stay in Wenchi as permanent tend to use cropping practices (which involve intercropping and/or rotation of yam and maize with cassava) which to some extent can regenerate soil fertility. On the other hand, the Walas who arrived in the area in the early 1990s and have strong ambition to return home use cropping practices (mainly continuous maize cropping with minimal external inputs) that tend to mine the soil of nutrients.

Among the natives, cropping systems and soil fertility management practices also differ significantly between male and female farmers. Although most female farmers are aware that maize and cowpea have more ready market than cassava and pigeonpea, they experience several obstacles in the cultivation of these crops including inadequate access to production resources such as labour, cash, credit and inputs (chemical fertilisers, herbicides and insecticides) which are essential for successful cultivation of maize and cowpea. They also consider the cultivation of these crops as risky farm enterprises due to the risk of crop failure as a result of unreliability of rains. For this reason, they resort to the cultivation of crops such as cassava and pigeonpea (which are less demanding with regards to labour and external inputs) and which can regenerate soil fertility to some extent (Adjei-Nsiah et al., 2007a). Native male farmers practise sole maize cropping for the market but in contrast to their migrant counterparts, they combine this with long term rotational strategies.

Farmers' evaluation of technical experiments

Figure 1 shows the effect of cropping sequence and N rate on maize grain yield and weed biomass associated with the maize crop 8 weeks after planting (Adjei-Nsiah et al. (2007a). According to these data, yields of maize were higher on plots previously cropped to cassava and pigeonpea compared with the other cropping sequences. The cropping sequences did not have significant effects on soil chemical properties. Figure 1 shows the effect of cropping sequence and N rate on maize grain yield and weed biomass associated with the maize crop 8 weeks after planting as determined by Adjei-Nsiah et al. (2007a). Returns on investment were also higher with cassava/maize and pigeonpea/maize rotations compared with the other rotations. Although yield of maize after Mucuna/maize/Mucuna was comparable to that after cassava, return on investment was far less than that obtained with cassava/maize, pigeonpea/maize or cowpea/maize/cowpea/maize due to the lack of returns during the period that Mucuna is growing in the field despite investments made in labour and input. It was therefore not surprising that none of the collaborating farmers expressed interest in using Mucuna as a soil fertility improvement strategy. Mucuna is a herbaceous legume which has been tested intensively over the past decade both as a green manure and as a short duration fallow in West Africa where it has been shown to increase maize grain yield considerably (Carsky et al., 1998; Fofana et al., 2005).

In the second experiment in which different cowpea varieties were evaluated, no significant differences in yield were observed among the different cowpea varieties, although differences were observed in the growth habit between the indeterminate creeping variety (Legon prolific) which matured after 90 days and the determinate erect varieties (Asontem, Ayiyi and IT810D-1010) which matured between 65-70 days (Adjei-Nsiah *et al*., 2007b). Legon prolific which produced twice the amount of stover as the erect varieties made the largest net N contribution to the overall soil N economy assuming all the above-ground foliage biomass were incorporated into the soil.

The criteria used by farmers to rank the varieties were similar among natives and migrants, with market value, short time to maturity, and yield being the three most important criteria in order of decreasing importance. Farmers noted that yields of maize after cowpea were consistently better than yields after maize. The farmers also observed a stronger effect of Legon Prolific in improving the yield of the subsequent maize crop compared with the other cowpea varieties. The economic benefits of Legon Prolific due to its residual soil fertility effects on improving the yield of the subsequent maize crop were demonstrated by simple economic analysis.

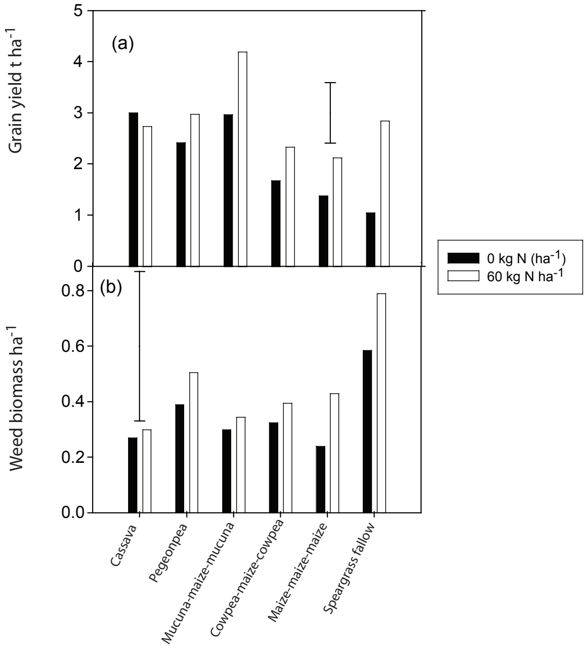

Figure 1. Effect of crop sequence and N rate on maize (a) grain and (b) weed biomass associated with the maize crop at 8 weeks after planting on researcher-managed plots. Vertical bars represent LSD between two crop sequence means at the same or different N rates at 5% level of significance (Adjei-Nsiah et al., 2007a)

Table 2. Farmers' selection of five cowpea varieties grown at Wenchi in the three villages; Asuano, Beposo and Droboso. (a) Farmers' criteria for selection; and (b) Number of farmers selecting various cowpea varieties. (N.B. for (a) the lowest scores indicate the best variety.)

(a)

Criteria	Ranking	
	Natives (n = 21)	Migrants (n =17)
Market value	1	1
Short maturity period	2	3
Yield	3	2
Taste	5	4
Ease of harvesting (plant height above the ground)	4	6
Tolerance to insect pests	6	5
Seed size	7	7
Pod length	8	8

(b)

Variety	Number of farmers			Percentage (%)	Reason for selection
	Natives (n = 10)	Migrants (n = 11)	Total (n = 21)		
Asontem	6	4	10	48	High yielding, early maturing
Adom	5	0	5	24	High yielding
Ayiyi	0	2	2	10	Early maturing
IT810D-1010	2	6	8	38	Sweet taste, early maturing, good market
Legon prolific	0	3	3	14	Leaves used as vegetable

Adjei-Nsiah et al., 2007b

Discussion

The entry point of this study was how to optimise locally developed technical strategies for dealing with soil fertility decline, after a study by Offei and Sakyi-Dawson (2002) revealed the existence of these practices, some of which contradict with what were perceived to be dominant scientific beliefs. For instance the use of cassava as a soil fertility regenerating crop seems to contradict the claim that cassava impoverishes soils (Hendershotte, 1972 cited by Nweke *et a*l., 2002; Sitompul, *et al.,* 1992).

During the initial diagnosis, we found significant differences between native and migrant farmers with respect to farmers' technical farming practices and attributed this to differential land tenure arrangements. However, continuous critical reflection and diagnosis during collaborative technical experimentation with farmers led to a progressive insight into a more complex situation. Consequently, we carried out further exploration of diversity among the farmers to deepen our understanding of soil fertility management. This further exploration revealed that what we initially interpreted as a problem of soil fertility decline and farmers' soil fertility management strategies' are in fact closely intertwined with practices, aspirations and strategies in totally different spheres (Adjei-Nsiah *et al*., 2007c). For instance, one of the migrant groups, the Walas have an active strategy to accumulate and export wealth to their communities of origin to which they expect to return which has important implications for soil fertility management. But their temporal outlook is likely at the same time to be a response to structural conditions such as how recently they migrated, increased scarcity of land in Wenchi, prevailing land tenure arrangements, and perhaps culturally ingrained meanings and/or expectations from family members. Similarly, female farmers' cropping strategies which involve the cultivation of crops such as cassava and pigeonpea may best be understood as coping strategies for dealing with 'structural' constraints such as dominant role divisions, food insecurity and high risks of crop failure, limited access to labour, and cash and credit. As other studies have shown (Jones and Sakyi-Dawson, 2001), women in Ghana -and in the forest savanna transitional agro-ecological zone in particular (see Asuming Brempong *et al*., 2004)- have limited access to credit. They therefore use root and tubers, particularly cassava as an ex-ante risk management strategy (Devereux, 2001). The dependence on root crops such as cassava as the most important source of on-farm income by female farmers may also be related to its relatively low labour demand (Berry, 1993: 187-188).

All the technical practices experimented with the farmers to some extent increased the yield of subsequent maize crop grown afterwards compared with yields on the plots previously under speargrass fallow or maize (Adjei-Nsiah *et al*., 2007a). The beneficial effects of cassava on maize grain yield were mainly due to the relatively high amount of recycled N returned to the soil through the leaf litter and green leafy biomass of cassava. Other possible effects may include reduction in weed incidence as a result of the suppression of weeds by the cassava canopy. Although we did not study the possible beneficial effects of mycorrhizal associations, there are indications that these could play a possible role as suggested by the very large initial effect of cassava on maize dry matter at 3 weeks after planting (Adjei-Nsiah *et al*., 2007a). Saïdou (2006) reported a major contributing effect of cassava on subsequent crops, potentially also through mycorrhizal associations.

The high return on investment obtained both with cassava/maize and pigeopea/maize rotations were due to high storage root yield of cassava and high grain yield of the pigeonpea as well as low labour and input requirements of these crops. However, despite of this high returns on investment, the migrant farmers in general, and the Walas in particular preferred the cowpea/maize rotation over both cassava/maize and pigeonpea/maize rotations although they acknowledge the superiority of the latter two over the former in terms of soil fertility improvements and maize grain yield. According to the Walas, the markets for cassava and pigeonpea are not always readily available and return on investment too slow. In addition, they are afraid that when they invest in the soil, they may not be allowed to reap the full benefits. Hence they prefer rotations involving short duration crops such as cowpea and groundnut which have ready market and quick returns.

According to Table 3, while both native female and male farmers prefer the cassava/maize rotation over all the others, they differed in their preferences mainly with respect to rotations involving the two most important food legumes, cowpea and pigeonpea (Adjei-Nsiah et al., 2007a).

Pigeonpea and cassava are also preferred by women because of their relatively lower labour demand. It is therefore rational for female farmers with inadequate access to production resources to adopt these rotational practices even if the market for these crops seems not to be well developed. Although there are no records to show which of the technical practices experimented with are being used by which group of farmers, during the preference ranking exercises carried out with the groups after

Table 3. Preferential ranking of different crop rotations by native and migrant farmers in three communities (Asuoano, Beposo and Droboso) in Wenchi

Management practice	Ranking order							
	Natives				Migrants			
	Asuoano[a] (n = 10)	Beposo[b] (n = 5)	Droboso[c] (n = 7)	Average	Asuoano[d] (n = 6)	Beposo[d] (n = 6)	Droboso[e] (n = 5)	Average
a) Ranking by natives and migrants								
Cassava-maize	1	1	1	1	2	2	1	1.7
Pigeonpea-maize	2	5	2	3	4	4	4	4
Mucuna-maize-mucuna-maize	7	6	4	5.7	5	6	6	5.6
Groundnut-maize-groundnut-maize	4	3	3	3.3	3	3	3	3
Cowpea-maize-cowpea-maize	3	2	5	3.3	1	1	2	1.3
Maize-maize-maize-maize	8	7	6	7	7	7	7	7
Cowpea-cowpea-cowpea-maize	5	4	7	5.3	6	5	5	5.3
Speargrass dominated fallow-maize	6	8	8	7.3	8	8	8	8

b) Ranking by female and male natives

	Females (n = 13	Males (n = 10)
Cassava-maize	1	1
Pigeonpea-maize	2	3
Mucuna-maize-mucuna-maize	5	7
Groundnut-maize-groundnut-maize	3	4
Cowpea-maize-cowpea-maize	4	2
Maize-maize-maize-maize	8	8
Cowpea-cowpea-cowpea-maize	7	5
Speargrass dominated fallow-maize	6	6

[a]Consisted of 6 males and 4 females; [b]Consisted of 4 males and 1 female; [c]Consisted of 6 females and 1 male; [d]Walas [e]Dagarbas

Source: Adjei-Nsiah et al., 2007a

the experimentation, different groups of farmers indicated which of the practices they would like to use. The preference for a particular practice depended on access to resources such as land, labour, credit, cash and input and the farmer's livelihood aspirations.

As has been pointed out by de Jager (2005), these low input technical practices can be seen as a defensive reaction to adverse economic conditions. According to de Jager (2005) these practices are relatively efficient at low productivity levels and are attractive to farmers when prices of outputs are low and prices of inputs are high.

Despite the larger benefit of cowpea varieties to subsequent maize, none of the farmer groups included this as an important criterion. When asked whether or not soil fertility improvement should be added to the list of criteria, the farmers responded negatively even if they were clearly aware that cowpea varieties differed in this respect. What informed farmers' choice of cowpea varieties for planting were more related to marketability, suitability for food, labour requirement and maturity. While the focus of scientists for introducing grain legumes into the farming system is to improve soil fertility for subsequent maize crop, the farmers' production objectives are for immediate food security need and cash income generation. Thus despite of the high leaf biomass production by Legon prolific, it was the least preferred variety by the farmers due to lower market price, late maturity, least potential cash income (due to the red motled seed type) and difficulty in harvesting. In the regions such as the northern Guinea savanna of Nigeria, where multipurpose cowpea varieties have been popular among farmers and have thus spread rapidly from village to village (Inaizumi et al., 1999), the reasons often stated for farmers' interest in such multipurpose varieties is the provision for fodder for livestock, improved soil fertility as well as grain for food or sale (Giller, 2001). However, in Wenchi, livestock play minor role and are poorly integrated in the farming systems which probably explain why forage production is not a criterion for selection of cowpea varieties.

Conclusions

The study which used participatory approaches initially focused on developing soil fertility management innovations that meet the needs and circumstances of farmers. However, insights generated through continuous exploration throughout the study showed that our initial notion about soil fertility management was far too narrow. Such a narrow framing reflects predominantly our own professional biases. What we initially conceived as 'soil fertility management' cannot be usefully separated from cropping systems, livelihood ambitions and land tenure relations.

Although farmers observed the soil fertility benefits of growing cowpea, they did not include this as a criterion in making their variety choice. The overriding criteria for selecting cowpea varieties were related to their early harvest, seed quality in terms of taste and marketability and ease of production (low labour demand). Our results thus confirms the suggestion (Giller, 2001) that soil fertility benefits of legumes must be considered as an 'additional benefit' rather than a primary criterion when designing more sustainable cropping systems together with smallholder farmers in Africa.

The findings of this study suggest that in most places in Africa where the populations of the farming communities are very heterogeneous designing one technology for enhancing soil fertility management may not suffice. Instead, efforts must be made to design a range of technical options that will meet the needs of different categories of people. The study further shows that agronomic results alone do not provide a complete picture when assessing a given technology and that there is the need to supplement these with socio-economic circumstances of farmers and farmers' own evaluations.

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Chapter 13

Impact Socio-economique des Technologies de Conservation des eaux et des Sols au Burkina Faso

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Résumé

La plupart des sols du Burkina Faso sont exposés à de fortes dégradations depuis de longues dates. Ainsi, depuis les années 1950, des actions multiformes tentent de palier aux impacts négatifs des activités anthropiques et de la péjoration du climat sur les ressources naturelles, notamment dans la partie septentrionale et au centre du pays. De nos jours, d'impressionnantes techniques de gestion des terres utilisant des techniques de conservation des eaux et sols (cordons pierreux, zaï, digues filtrantes, demi-lunes, haies vives, paillage, diguettes en terre, tranchées de reboisement, haies vives, banquettes, plate-forme (ou buttes) et mise en défens sont partout présentes en milieu rural. On peut estimer les superficies aménagées dans le Plateau Central entre 250.000 et 300.000 ha. Il existe un consensus général quant aux impacts des techniques de CES sur la production, le revenu et la sécurité alimentaire des populations. En effet, elles sont apparues comme une réponse efficace à la pression démographique, à la dégradation des terres, à la baisse de la fertilité des sols et aux déficits céréaliers dans la région du Plateau Central. De ce fait, elles ont eu des impacts importants en milieu rural, si l'on en juge non seulement par l'engouement qu'ils ont suscité auprès des populations, mais également par les résultats sur le milieu physique, socio-économique et sur la production agricole. Pourtant, la quantification des ces impacts, particulièrement des impacts socio-économiques reste un sujet très complexe, d'autant plus que les statistiques agricoles sont presque inexistante. L'analyse coût-bénéfice réalisée à partir des données transversales de différentes sources montre que le zaï et les cordons pierreux ont des impacts positifs sur les revenus, sur la sécurité alimentaire des populations et sur le tissu social des villages. En effet, la valeur brute du surplus de production est de 36048 FCFA pour la culture du mil en première d'application du zaï. Cette valeur est comprise entre 36048 et 133951 selon que le rendement se stabilise à 1000 kg/ha où qu'il se situe à 1700 kg/ha en deuxième année. Pour les cordons pierreux, la valeur brute du surplus de production est estimée à 39500 FCFA pour le mil et à 12270 FCFA pour le sorgho. Pour ce qui est de la sécurité alimentaire, le taux de couverture a été de 110,7% chez les ménages sans aménagement CES et de 125,4% chez les ménages avec CES en 1995-96 (année de bonne pluviométrie contre 48,78% chez les ménages sans CES et de 63% en 1996-97 (année de mauvaise pluviométrie). A l'échelle de la zone d'intervention du programme spécial CES/AGF, les aménagements permettent de couvrir les besoins alimentaires de 42000 à 43000 personnes par an. Les aménagements de CES ont également favorisé la création de cadres idéals de dialogue et de renforcement du tissu social, ainsi que le développement d'autres initiatives collectives. Un peu partout, des associations ont vu le jour pour promouvoir par le biais de prestation de service certaines technologies de CES.

Mots clés: *Burkina Faso, conservation des eaux et sols, socio-économique*

Abstract

Most soils of Burkina Faso are exposed to land degradation. Since 1950, some multiform actions tempt to overcome the negative impacts of Human activities and the depletion of the climate on the natural resources, particularly in the northern and in the central part of the country. Nowadays, impressive soil and water conservation (SWC) technologies management (stone rows, zaï, dams for gully control, half moon, living hedges, mulching, earth barriers, reforestation, wood barriers, platform (or mounds) and setting in defense) are everywhere present in farming environment. The surfaces cover by these land management technologies can be estimate between 250.000 and 300.000 ha. A general consensus exists on the impacts of soil and water conservation technologies on production, income and food security of the populations. They appeared like an efficient answer to the demographic pressure, to the deterioration of the land, to the decrease of soil fertility and to the deficits of cereal in the region of the Central Plateau. They had important impacts in farming environment, if we judge by the interest demonstrate by the populations, but also by the results on the physical, socioeconomic environment and on agricultural production. The quantification of these impacts, especially, the socioeconomic impacts remained a very complex topic as the agricultural statistics are non-existent. The cost-profit analysis realized from the transversal data of different sources show that the zaï and the stony cords have positives impacts on incomes, on food security of the populations and on the social relation of the villages. The surplus value of the production is of 36048 FCFA for on ha of millet in the first year of application of the zaï. This surplus value is between 36048 and 133951 CFA depending on whether the output stabilizes to 1000 kg/ha where that it is located to 1700 kg/ha in second year. For the stony cords, the surplus value of the production is estimated to 39500 FCFA for one ha of millet and 12270 for one ha of sorghum. Food security rate was to 110,7% for households without SWC technologies and 125,4% for households with SWC technologies in 1995-96 (year of good raining season) against 48,78% for households without SWC and 63% in 1996-97 (year of bad raining season). To the scale of the area cover by the program special CES/AGF, SWC technologies has contributed to cover the food needs of 42000 to 43000 people per year. SWC has developed new partnership among population and their organization and encouraged the establishment of dialogue and backing of the social relation as well as the development of other collective initiatives. Almost everywhere, some associations are promoting SWC technologies

Key words: *Burkina Faso, Socio-economic, soil and water conservation*

Introduction

Estimée à près de 12,3 millions d'habitants en 2001, pour une densité moyenne de 44,8 habitants par km^2, la population du Burkina Faso est à très forte proportion rurale (86%). L'essentiel de l'économie est basé sur les productions agricoles, en majorité pluviales et donc tributaires des aléas climatiques. La pluviométrie annuelle varie selon un gradient nord-sud d'aridité décroissante de 400 à 600 mm pendant 3 à 4 mois au Nord, et de 1000 à 1300 mm pendant 5 mois à l'extrême Sud-Ouest. Un peu plus de la moitié du pays se situe au nord de l'isohyète 700 mm. L'élevage y est à majorité de type traditionnel, extensif ou semi-extensif (transhumant ou sédentaire) avec des pâturages naturels en situation bien souvent concurrentielle, voire conflictuelle avec les terres agricoles.

Comme tous les pays du Sahel, la plupart des sols du Burkina ont été exposés à de fortes dégradations depuis de longues dates. Ainsi, des années 1962 - 1970 à nos jours, des actions multiformes tentent de palier aux impacts négatifs de la péjoration du climat et des activités anthropiques sur les ressources naturelles, notamment dans la partie septentrionale et au centre du pays. L'intérêt pour cette partie du pays se justifie par la pression exercée par les populations sur les superficies cultivées et les méthodes culturales qui conduisent à la «stérilisation» des sols se traduisant par la présence de vastes étendues de sol dénudé (Zipellé).

Depuis lors, pour minimiser d'une part les risques climatiques (irrégularité de la pluviométrie) et d'autre part garantir un niveau de production acceptable, les ONG, associations et projets se sont impliqués activement dans les actions de lutte contre la dégradation des terres à travers les reboisements, l'agroforesterie, les cordons pierreux, la conservation de la biodiversité. D'importants investissements financiers et humains ont été alors consentis pour la mise au point et la diffusion des technologies de conservation des eaux et des sols. On estime aujourd'hui à plus de 300.000 ha les superficies aménagées dans le Plateau central du Burkina Faso. Il s'agit aussi bien de techniques mécaniques que techniques biologiques de conservation des eaux et des sols. Ces actions ont été entreprises dans l'optique non seulement de conserver et d'améliorer la base productive mais également d'accroître la productivité agricole. Si l'unanimité semble se dégager sur les impacts positifs des aménagements sur l'érosion hydrique, l'amélioration de fertilité des sols et du couvert végétal, il n'en demeure pas moins que ceux sur les productions et les revenus des producteurs restent insuffisamment documentés.

L'objectif de ce travail est de voir quel a été l'impact des techniques de CES sur les rendements des cultures (aspect physique) et l'impact économique et social qui en résulte. En effet, pour les producteurs, ce sont surtout les impacts des aménagements sur la production agricole et la sécurité alimentaire qui suscitent leur intérêt pour les techniques de CES, alors que les acteurs impliqués dans la réalisation de ces actions (bailleurs, Etat) se posent des questions sur les effets et la durabilité des impacts significatifs. Par exemple, l'Etat a besoin de ces résultats afin de fonder ses choix sur les technologies sûres étant donné ses moyens limités et l'urgence de ses obligations socio-économiques. Avant d'aborder ces différents aspects, un bref aperçu sera fait sur ces techniques de CES.

L'inventaire et description de quelques techniques de CES

Au Burkina Faso, il existe une abondante diversité de techniques de CES qui sont mises en œuvre par les populations. Ces différentes techniques ont fait l'objet de diverses descriptions dont Vlaar (1992), Rochette (1989), Marchal (1986), Reij (1983), Roose (1994), Ouédraogo et Millogo (2007).

Parmi ces techniques, on peut citer, les cordons pierreux, le zaï, les digues filtrantes, les demi-lunes, les haies vives, le paillage, les diguettes en terre, les tranchées de reboisement, les haies vives, les banquettes, la plate-forme (ou buttes) et la mise en défens. Ces techniques ont été vulgarisées dans plusieurs pays de la région sahélienne dans l'objectif de préserver les ressources naturelles et d'accroître la production agricole.

- *Les cordons pierreux* : ce sont des barrières mécaniques d'arrêt ou de freinage des eaux de ruissellement placées le long des courbes de niveau, pour réduire l'érosion et augmenter le stock d'humidité du sol. Les pierres sont disposées dans des tranchées de 10 à 15 cm de profondeur. La largeur d'un cordon est d'environ 15 à 20 cm et la longueur varie entre 10 et 30 m. La disponibilité en main-d'œuvre et la présence de cailloux constituent les facteurs limitants. Les cordons pierreux entraînent une réduction du ruissellement, facilitent l'infiltration de l'eau dans le sol et favorisent une accumulation des particules en amont des diguettes. L'état hydrique du sol permet aux cultures de supporter des épisodes de sécheresse et d'avoir un développement végétatif normal. L'impact sur les rendements varie de 20 à 50%. Plusieurs ligneux poussent le long des ouvrages traduisant la régénération favorisée par les aménagements. Dans la zone d'intervention du projet PATECORE, ce nombre est estimé à 11 pieds pour 100 m de cordons pierreux en moyenne.
- *Le zaï* : il consiste à creuser des trous larges de 20 à 30 cm de diamètre et de 15 cm de profondeur, dans lesquels est déposé du compost ou de la poudrette issue des déjections des animaux et des ordures ménagères. Les termites, attirés par la matière organique, creusent des galeries au fond de la cuvette qu'ils transforment en entonnoirs. Les eaux de ruissellement y pénètrent, créant des poches d'humidité en profondeur, à l'abri de l'évaporation, ce qui entraîne une amélioration des propriétés hydrodynamiques du sol. L'effet conjugué de la matière organique et de l'humidité permet une meilleure implantation des semis. C'est pourquoi les re-semis et les conséquences des accès précoces de sécheresse sont souvent évités. Les rendements augmentent de façon spectaculaire (50 à plus de 100%). Répété plusieurs années sur le même sol, le zaï permet de reconstituer la fertilité du sol et le couvert végétal. L'inventaire des adventices réalisé par Trouillier (2003) fait ressortir l'apparition de plusieurs espèces herbacées sur les parcelles aménagées tandis que les parcelles témoins restent nues.

Lors de la confection des trous, les paysans doivent tenir compte de certains facteurs tels que la toposéquence et l'écartement (selon qu'ils envisagent ou non d'utiliser la traction animale). Le zaï est généralement pratiqué sur sol gravillonnaire, mais il est de plus en plus généralisé sur tous les types de sols pour minimiser le déficit hydrique. Le zaï exige une main-d'œuvre importante.

- *Les demi-lunes* : ce sont des cuvettes en demi-cercle creusées et ceinturées avec les déblais disposés en arc de cercle ouvert à l'amont. Le creux recueille l'eau piégée par les bras de la demi-lune. L'amont du creux sert d'impluvium. L'association entre un impluvium inculte qui reçoit l'eau de pluie et la partie creusée et travaillée où elle est retenue en sont les éléments principaux de ce dispositif. Les demi-lunes sont généralement disposées en quinconce sur les versants, de façon à retenir toutes les eaux de ruissellement ; ce qui permet aux plantes cultivées dans la demi-lune de recevoir plus d'eau que ne lui apportent directement les pluies. Les demi-lunes entraînent non seulement l'accroissement des rendements mais également l'apparition d'un couvert végétal. L'apport de matière organique facilite le développement d'une flore importante. La demi-lune peut avoir un rayon allant de 2 à 3 mètres et une profondeur de 30 à 40 cm. Tout comme le zaï, la confection des demi-lunes est un gros labeur et demande beaucoup de main-d'œuvre.
- *La haie vive* : elle est traditionnellement utilisée pour délimiter des parcelles ou des jardins, généralement de petites superficies. Elle joue un rôle de brise-vent. Elle contribue aussi à la conservation et à la restauration des sols en ralentissant le ruissellement des eaux de pluie et en réduisant l'érosion.
- *Le paillage* consiste à recouvrir le sol d'une couche de 2 cm d'herbes équivalant de 3 à 6 t/ha ou de branchages ou encore de résidus culturaux (tiges de mil ou de sorgho) de façon à stimuler l'activité des termites. Ces derniers vont casser la croûte superficielle du sol en creusant des galeries sous les paillis. Il en résulte un ameublissement du sol et une augmentation de sa porosité qui permettent une meilleure infiltration de l'eau (Zombré et al, 1999). L'application du paillis dans les zones semi-arides du Sahel, où l'érosion éolienne est présente, entraîne une accumulation de particules sous forme de sédiments sous les paillis (Mando et Stroosnijder, 1999). Le paillage entraîne également la réhabilitation de la végétation dès la première année d'application (Mando et Brussard, 1999) et un développement de végétation couvrant complètement un sol nu dans un délai de deux ans. Cette performance de la végétation sous paillis est la réponse de celle-ci à l'effet du paillage sur l'amélioration de la structure du sol et sur la disponibilité en eau et en nutriments dans le sol.
- *La Régénération Naturelle Assistée (RNA)* conseillée par les services étatiques (agriculture, eaux et forêts) consiste à épargner certains arbustes (arbres utiles et à usages multiples), de façon à reconstituer un couvert ligneux sur les champs. Selon les producteurs, une petite densité d'arbres dans les champs contribue à freiner l'écoulement de l'eau, donc à réduire l'érosion tout en permettant une restauration de la diversité biologique.
- *La plantation d'arbres ou reboisement* : il s'agit surtout de la plantation d'arbres

fruitiers. Selon la coutume, ces plantations consacrent l'appropriation effective et individuelle de la terre.

- *Les bandes enherbées* : ce sont des bandes de végétation permanentes d'herbes et d'arbustes établies le long des courbes de niveau dans les champs. Disposées perpendiculairement au sens des écoulements diffus et suivant des critères adéquats liés aux sols, aux pentes, à l'occupation du sol et aux pluies, les bandes enherbées favorisent trois types de processus :
  - le ralentissement du ruissellement diffus de surface qui les traverse, du fait de la rugosité de surface importante de la végétation de la bande enherbée ;
  - la diminution éventuelle de ce flux de ruissellement diffus, par infiltration accrue due à la présence d'une végétation dense ;
  - le dépôt de sédiments du fait des deux processus précédents.

  Les bandes enherbées jouent un rôle important pour les terrains drainés et ne trouvent leur pleine efficacité qu'en fonction de la topographie des lieux et de la nature des sols. Leur efficacité dépend aussi de leur largeur.

- *La plate forme (butte)* : Il s'agit d'une technique endogène d'aménagement typiquement adaptée à la mise en valeur agricole des bas-fonds inondables à sols profonds. Les plates formes sont des monticules de terre de forme arrondie ou rectangulaire dont la superficie varie de 6 à 11 m2 pour une hauteur moyenne de 50 cm (Hien et al., 2000).

Quels sont les critères qui guident les choix des techniques de CES par les producteurs

Pour favoriser l'introduction et l'extension des techniques de CES, il est indispensable de connaître les critères qui déterminent les préférences des paysans pour les différentes techniques de CES. Pour ce faire, Ouédraogo et al. (2002) ont utilisé la méthode de la « classification préférentielle des technologies » auprès d'un échantillons de 200 producteurs. Le Tableau 1 donne les résultats de cette classification. Il ressort de ce travail que les producteurs apprécient l'impact des aménagements de CES à travers les critères d'amélioration de la fertilité, de productivité et la durabilité de l'ouvrage. Ainsi les techniques les plus appréciées sont par ordre de priorité les cordons pierreux, le zaï, le paillage, la régénération naturelle assistée (RNA) et les diguettes en terre. Comme on peut le constater, ces critères prennent en compte simultanément les objectifs à moyen terme (fertilité) et de long terme (durabilité). Les cordons pierreux sont reconnus pour leur impact à moyen et long terme, tandis que le zaï et le paillage ont des effets immédiats sur la production agricole. Les producteurs évaluent donc les techniques de CES en fonction des flux de production agricole futurs qui n'auraient pas existés sans elles. C'est ce qui explique que de ces différentes techniques, les cordons pierreux, le zaï, le paillage et dans une moindre mesure l'agroforesterie soient les plus répandus dans le Plateau central du Burkina Faso

Tableau 1: Classification potentielle des différentes technologies par les hommes

Technologies de CES/AGF	Critères de préférences				Totaux	Moyennes
	Rendement élevé	Fertilité améliorée	Humidité conservée	Durabilité		
Paillage	+++	++++	+++	+	++++++ +++++	2,75
Agro-foresterie/ RNA		++	+	+++++	++++++++	2
Zaï et fumure organique	++++	+++++	+++	+	+++++ ++++++++	3,25
Cordons pierreux	++	+++	++++	+++++	+++++++ +++++++	3,5
Diguettes en terres	+	+	++	+++	+++++++	1,75
Pondération totale	+++++ + ++++	+++++++ ++++++++	+++++++ ++++++	+++++++ ++++++++		
Moyennes	2	3	2,6	3		

Source: Ouédraogo et al., 2002

L'impact physique et économiques des techniques de CES

Au Burkina, Il existe un consensus général quant aux impacts des techniques de CES sur la production, le revenu et la sécurité alimentaire des populations. En effet, elles sont apparues comme une réponse efficace à la pression démographique, à la dégradation des terres, à la baisse de la fertilité des sols et aux déficits céréaliers dans la région du Plateau Centrale. Pourtant, la quantification de leurs impacts reste un sujet très complexe, d'autant plus que les statistiques agricoles sur les nouvelles technologies sont presque inexistantes. Pour évaluer de manière satisfaisante l'impact des technologies en générale et particulièrement celles de CES, des données collectées à partir de dispositifs statistiques dans différentes régions agro climatiques et sur plusieurs années auraient été nécessaires, ce qui n'est pas le cas. C'est ce qui explique que pour la présente étude, les données utilisées sont soit des données secondaires collectées de façon ponctuelle soit des compilations diverses de sources déjà existantes. Elles sont souvent présentées sous forme agrégée[1] et parfois individuellement.

L'une des caractéristiques des techniques de CES dans le Plateau Central est leur manque de stabilité des rendements. En effet, la variabilité est si importante que dans le même espace, les rendements peuvent fluctuer du simple au double en fonction de la pluviométrie, du type de sols et de la maîtrise de la technologie.

La présente évaluation s'intéressera à l'impact agrégé techniques de CES, du zaï et des cordons pierreux.

L'impact agrégé des CES

Les aménagements avec les techniques de CES d'une manière générale, ont eu des impacts importants en milieu rural, si l'on en juge non seulement par l'engouement qu'ils ont suscité auprès des populations, mais également par les résultats sur le milieu physique, socio-économique et sur la production agricole. Sur le plan physique, déférents auteurs (Somé et al, 1998; Ouédraogo et al., 2001) notent une diminution de l'érosion, la reconstitution des sols, la régénération des ligneux et herbacées, la remontée de la nappe phréatique et des eaux souterraines, la rétention de l'humidité sur les sols aménagés et l'amélioration de la fertilité des sols.

L'impact sur les rendements

Impacts des aménagements sur les rendements agricoles a suscité l'intérêt des producteurs pour les techniques de CES. Une évaluation de l'impact « agrégée », c'est à dire de l'ensemble des CES (cordons pierreux, zaï, demi lune) dans le Plateau Central a été réalisée par différentes structures de développement telles que les projets CES/AGF et PATECORE. Le Tableau 2 présente les résultats obtenus par le programme CES/AGF sur trois campagnes agricoles et sur 360 parcelles paysannes.

Tableau 2: Rendements des cultures céréalières (kg ha^{-1}) avec les techniques de CES, moyenne sur 360 parcelles

Cultures	95/96		96/97		97/98	
	Rdt (kg ha^{-1})	Accr. (kg)	Rdt (kg ha^{-1})	Accr (kg)	Rdt (kg ha^{-1})	Accr. (kg)
Champs de case et de village						
Sorgho blanc	1066	+77	558	+144	613	+199
Sorgho rouge	1303	+167	790	+110	nd	nd
Mil	744	+13	304	(-30)	283	(-51)
Champs de brousse						
Sorgho blanc	887	+181	301	(-72)	493	(- 103)
Mil	656	+38	406	+ 43	526	+ 45

**accroissement du rendement par rapport au témoin sans aménagement*

(-) ces chiffres impliquent qu'il y a plutôt eu un effet dépressif des cordons pierreux sur la production. Ceci est particulièrement vrai pour le mil qui ne supporte pas l'excès d'eau.

Source: PS CES-AGF (2000)

Il ressort du tableau 2 que les aménagements ont eu un impact positif sur les rendements du sorgho dans les champs de case, mais dépressif sur le mil. On assiste par contre à l'effet inverse dans les champs de brousse, où l'impact des aménagements est positif sur le mil, mais négatif sur le sorgho.

D'une manière générale, le rendement moyen du sorgho sur l'ensemble des trois campagnes a été de 788 kg ha^{-1} sur les terres aménagées contre 685 $kgha^{-1}$ aux terres non aménagées ce qui représente un accroissement de près de 15%. Ces rendements ont été respectivement de 477 kg ha^{-1} et de 472 kg ha^{-1} pour le mil. L'impact des techniques CES sur la culture du mil reste mitigé.

La même tendance s'observe dans la zone du projet PATECORE (1999) où le rendement moyen du sorgho sur les terres aménagés a été de 774 kg ha^{-1} contre 651 sur celles non aménagées ; ce qui représente une augmentation de l'ordre de 19 %. Les rendements du mil sur les terres aménagées ont été inférieurs à ceux des témoins (470 kg ha^{-1} contre 531 kg ha^{-1}).

La baisse des rendements observés sur le sorgho serait probablement due à la baisse de la fertilité des sols sous aménagement dans les champs de brousse. En effet, sans un apport de fertilisants, les rendements baissent avec l'âge des aménagements. Ce qui explique que les rendements diminuent sur les champs de brousse et non sur les champs de case qui reçoivent la fumure organique et les ordures ménagères. Pour ce qui est du mil, en plus de la baisse de la fertilité, il y a également l'excès d'eau ou d'humidité dû aux aménagements.

Bien que les gains de rendements dus aux CES paraissent faibles, il est important de signaler qu'il s'agit de rendements moyens, mais qui restent substantiels dans certains cas. En terme de production, ils représentent annuellement 7700 à 8200 tonnes de céréales pour la seule zone couverte par le programme CES/AGF. Il faut également garder à l'esprit que, l'objectif premier des aménagements est la conservation du capital de production même si par ailleurs on s'attend à l'accroissement de la productivité de la terre.

L'impact des techniques de CES sur les revenus

Sur la base des gains de rendement du tableau 1, il a été possible de déterminer l'impact des techniques de CES sur les revenus des producteurs en leur donnant une valeur monétaire (Tableau 3). Ainsi, les revenus bruts additionnels dus aux aménagements sont de 11200 $FCFA/ha^2$ pour le sorgho blanc; 11355 pour le sorgho rouge et une perte de 2040 FCFA /ha pour le mil. Ces résultats corroborent ceux d'autres sources, notamment le rapport d'évaluation à mi-parcours du programme CES/AGF (Tableau 4). Ces revenus additionnels bien qu'assez faibles ne sont pas négligeables pour le producteur surtout dans un pays où la majorité de la population vit avec moins d'un dollar par jours.

Tableau 3: Revenus bruts additionnels dû aux techniques de CES

Cultures	95/96	96/97	97/98	Moyenne 95/98
Champs de case et de village				
Sorgho blanc	6160	11520	15920	11200
Sorgho rouge	13360	9350	nd	11355
Mil	1170	- 2700	- 4590	- 2040

Source : Construction de l'auteur

Tableau 4: Impact financier des mesures de CES

	Produit brut (FCFA)	Coût de production (FCFA)	Revenu net (FCFA)	Revenu/ha (FCFA)
Sans CES	76023	3050	72973	24324
Avec CES	150060	22410	127650	34040

Source : Rapport d'avancement à mi-parcours du PS/CES-AGF, 1999[3]

L'impact des techniques de CES sur la disponibilité alimentaire

L'un des objectifs recherché dans la mise œuvre des techniques de CES est non seulement la sécurisation mais également l'accroissement de la production agricole. Elles ont de ce fait contribué à améliorer le taux de couverture des besoins céréaliers des ménages. Le tableau 5 montre qu'en 1995-1996 (année de bonne pluviométrie), le taux de couverture a été de 110,7% chez les ménages sans CES et de 125,4% chez les ménages avec CES. Ces chiffres étaient de 48,78% chez les ménages sans CES et de 63% en 1996-97 (année de mauvaise pluviométrie). Les aménagements contribuent donc à augmenter les rendements en année de bonne pluviométrie et à les sécurisés en année de mauvaise pluviométrie.

A l'échelle de la zone couverte par le programme CES/AGF, le gain de production dû aux aménagements varie annuellement entre 7763 et 8211 tonnes (Ouédraogo 1994). Ce qui représente la couverture des besoins alimentaires de 42000 à 43000 personnes sur base de 190 kg de céréales par individu.

Tableau 5: Impact des techniques de CES sur le taux de couverture des besoins céréaliers des ménages

	Ménages sans CES		Ménages avec CES	
Cultures	1995-1996	1996-1997	1995-1996	1996-1997
Sorgho blanc (kg)	1732,8	575,5	1735,0	909,8
Sorgho rouge (kg)	90,8	54,4	13,5	5,9
Mil (kg)	646,0	298,4	640,8	277,5
Production totale (kg)	2109,6	928,3	2389,3	1193,2
Total disponible (kg)*	1793,16	789,05	2030,91	1014,22
Besoin alimentaire (kg)	1620,0	1620,0	1620,0	1620,0
Taux de couverture du besoin alimentaire (%)	110,7	48,78	125,4	63,0

Source: Ouédraogo, 1999[4]

Le zaï

L'impact du zaï sur les rendements

Le zaï est l'une des technologies la plus connue et adoptée dans le Plateau Central du Burkina Faso. Les Tableaux 6 et 7 présentent les rendements des cultures de mil, maïs et sorgho sous (et sans) aménagement zaï issus de différentes sources. Les augmentations de rendements peuvent varier du simple au double. Pour illustrer ces augmentations deux sources de données ont été utilisées. Les travaux de l'Institut de l'Environnement et de Recherches Agricoles (INERA)[5] 1994 et la compilation de diverses sources réalisée par Requier-Desjardins et Bied-Charreton en 2005

Les travaux de l'INERA font ressortir que le zaï entraîne un accroissement de rendement de 86% dans le Plateau Central (Tableau 6). Ce qui fait de ce dernier une technologie prometteuse pour cette région du Burkina Faso. Associé au paillage, le zaï donne également de bon rendement 1050 kg ha^{-1} contre 668 kg ha^{-1} pour le témoins soit un accroissement de près de 57%. L'association avec la paille semble avoir eu un effet dépressif sur le rendement du zaï.

Les résultats de la compilation de Requier-Desjardins et Bied-Charreton en 2005 donnent un accroissement de rendement de 300 kg (soit 42%) en première année de zai et de 1000 kg (143%) en deuxième année (Tableau 7).

Tableau 6: Rendements (kg ha^{-1}) du sorgho sous différents types de CES

	Témoin	**Zaï**	**paillage**	**Paillage brûlé**	**Zaï + paillage**
Moyenne	668	1241	704	681	1050
Maximum	3170	4365	3313	1319	2533
Minimum	42	147	38	151	320
Ecart type	535	932	488	301	554

Source: INERA, RSP Centre, 1994

Tableau 7: Rendement des cultures avec et sans zaï

Mil	2000 (sans zaï)	2001 (avec zaï)	2002 (avec zaï)
Rendement (kg ha^{-1})	700	1000	1000 à 1700
Maïs			
Production (kg ha^{-1})	700	1000	1000 à 1700

Source: construction de l'auteur à partir des données de Desjardins et Charreton

L'impact du zaï sur les revenus

A partir des résultats de tableau 7, Requier-Desjardins et Bied-Charreton ont estimé l'impact du zaï sur le revenu net des ménages. En première année de zaï, la valeur brute du surplus de production est de 36048 FCFA pour la culture du mil. En deuxième année, cette valeur est comprise entre 36048 et 133951 selon que le rendement se stabilise à 1000 kg ha^{-1} où qu'il se situe à 1700 kg ha^{-1}.

Le coût du zaï est évalué à 100.000 FCFA/ha, avec 1.000 à 4.000 heures de travail par hectare soit 167 à 571 journées de travail de 6 heures. En effet pour le zaï, le coût de la main d'œuvre est de 797 FCFA pour une journée de 6 heures, soit 133 FCFA/h pour un coût d'opportunité de la main d'œuvre de 100 FCFA (Desjardins & Charreton, 2005). Sur cette base, la valeur brute due surplus de production de la première année ne permet pas de compenser l'investissement dans lu zaï. Par contre en deuxième année, la valeur du surplus de production du mil (au cas où le rendement serait de 1700 kg/ha, hypothèse haute) permet au producteur de récupérer son investissement. Mais dans le cas de l'hypothèse basse, le producteur ne récupère pas toujours son investissement. Les mêmes conclusions restent valables pour la culture du sorgho.

Tableau 8: Effet du zaï sur la production des céréales et sur le revenu agricole

Mil	2000 (sans zaï)	2001 (avec zaï)	2002 (avec zaï)
Production (t) à l'ha	0,7	1	1,7 ou 1
Valeur de la production	52784,9	120161	227718 ou 133952
Valeur surplus de production		36048	133951 ou 40185
Total des dépenses		100000	100000
Surplus de revenu		-63952	+33951
Maïs			
Production (t) à l'ha	0,7	1	1,7 ou 1
Valeur de la production	46431	99455	190972 ou 112337
Surplus de production		29836,5	112337 ou 33701
Total dépenses		100000	100000
[2]Surplus de revenu		-70163	12337

Source: construction de l'auteur à partir des données de Desjardins et Charreton

Les cordons pierreux

L'impact des cordons pierreux sur les rendements

Les cordons pierreux, comme l'illustrent les tableaux 9 et 10 ont un impact positif sur les rendements. L'augmentation de rendement serait de 329 kg (47%) pour le mil et 114 kg (11%) pour le sorgho.

Tableau 9: Rendements (en kg/ha) du mil et sorgho sous cordons pierreux

Mil	2000 (sans CP)	2001 (sous C.P[6])	2002 (sous C.P)
Rendement (kg ha^{-1})	700	1029[7]	1029
Sorgho			
Rendement (kg ha^{-1})	1016[8]	1130[9]	1130

Source : construction de l'auteur à partir des données de Desjardins et Charreton

L'impact des cordons pierreux est encore plus important lorsqu'ils sont associés à la fumure organique. Le sorgho blanc connaît un accroissement de rendement de 109 kg, 364 kg pour le sorgho rouge et 83 kg pour le mil par rapport à la situation sans fumure organique.

Tableau 10: Rendement des cultures céréalières sous cordons pierreux + fumure

Cultures	95/96		96/97		97/98	
	Rdt (kg ha^{-1})	Accr. (kg ha^{-1})	Rdt (kg ha^{-1})	Accr. (kg ha^{-1})*	Rdt (kg ha^{-1})	Accr. (kg ha^{-1})
Champs de case et de village						
Sorgho blanc	1098	109	832	418	625	251
Sorgho rouge	1500	364	nd	nd	nd	nd
Mil	814	83	360	26	307	51
Champs de brousse						
Sorgho blanc	1031	225	700	327	648	276
Sorgho rouge	1553	573	nd	nd	nd	nd
Mil	1040	422	nd	nd	nd	nd

Source : CES/AGF[10]

L'impact des cordons pierreux sur les revenus

En se basant sur les données du tableau 10, la valeur brute du surplus de production dû aux cordons pierreux est de 39533 pour le mil et de 12269 pour le sorgho (tableau 11).

Les coûts d'un ha de cordon pierreux est estimé à 32000 Fcfa par le projet PATECORE . Ce coût prend en compte le transport des pierres et la main d'œuvre. La charge de travail pour les cordons pierreux fait en individuel est de 97 heures par hectare, et de 673 heures par hectare pour les cordons collectifs financés par les projets de développement. Sur cette base l'amortissement des dépenses pour la mise en place des cordons pierreux est de 6400 FCFA/ha/an pour le projet PATECORE en supposant que la durée de vie des cordons pierreux est de cinq ans.

Le surplus de revenu en première année pour le mil est de 33132 FCFA dans le projet PATECORE. Le surplus de revenu réalisé en première année pour la culture du sorgho est de 5869 FCFA.

Si avec le mil l'investissement est récupéré dès la première année, pour le cas du sorgho, il faudrait attendre la cinquième année pour récupérer la totalité de l'investissement.

Tableau 11: Effet des cordons pierreux sur la production des céréales et sur le revenu

Mil	2000	2001(sous C.P)	2002 (sous C.P)
Production (t)	0,7	1,029[11]	1,029
Valeur de la production		123645	77593
Surplus de production		39532	24808
Total dépenses		6400	6400
Surplus de revenu		33132	18408
Sorgho			
Production (t) à l'ha	1,016[12]	1,13[13]	1,13
Valeur de la production	100570,93	121615,12	
Surplus de la production		12269,13	13954,85
Total dépenses		6400	6400
Surplus de revenu		5869,13	7554,85

Source: construction de l'auteur à partir des données de Desjardins et Charreton

Impact social des techniques de CES

Du fait de leur nature à la fois collective et individuelle, les activités d'aménagements ont fini par créer un cadre idéal de dialogue et de renforcement du tissu social, ainsi que le développement d'autres initiatives collectives. Un peu partout, des associations ont vu le jour pour promouvoir par le biais de prestation de service une technologie précise de CES. Par exemple l'association Zaï à Lougouri vend ses services à ses membres sous forme d'entraide ; pour deux heures de prestation de services dans le champ d'un de ses membres pour faire le zaï, le bénéficiaire paye la somme de 250 FCFA au profit de la caisse de l'association. Le groupement des femmes également méne des activités d'entraide pour cultiver les champs de leurs maris sous forme de contrat dont les montants varient entre 750 et 10000 FCFA.

Les aménagements collectifs ont contribué énormément à sensibiliser et à démontrer aux populations la pertinence des actions de CES. De même, l'action des intervenants a favorisé le renforcement des compétences individuelles et collectives, mais elle a surtout renforcé la cohésion sociale au niveau des villages.

Conclusion

Les populations du Plateau Central sont confrontées à deux problèmes importants que sont la conservation du potentiel écologique et la satisfaction des besoins alimentaires. Ceci explique l'adoption à grande échelle des techniques de CES par les producteurs, certes, en raison de l'état avancé de la dégradation des terres, mais également de leur impact sur la sécurité alimentaire. Les différences de rendements entre les parcelles aménagées et celles non aménagées restent cependant assez modestes, mais rapporté à l'ensemble de la zone aménagé, le gain de production permet de couvrir annuellement les besoins alimentaires de 42000 à 43000 personnes, ce qui est très substantiel surtout dans une région où les populations sont confrontées permanemment à des déficits céréaliers. Dans certains cas, les gains de production ont favorisé la constitution de revenus à partir de la vente des excédants céréaliers.

Le défi majeur actuel est donc d'augmenter les rendements des techniques de CES disponibles par des changements dans les techniques et les méthodes de production afin de maximiser la production, la sécurité alimentaire et les revenus. Par exemple, l'utilisation de la fumure organique dans les parcelles aménagées procure plus de rendement par rapport á celles aménagées mais sans apport de fertilisants. Les producteurs sont conscients que la combinaison de plusieurs techniques de CES sur une même parcelle donne de meilleurs rendements que lorsqu'elles sont appliquées individuellement. Ces combinaisons restent cependant limitées en raison de la pénibilité du travail, d'où la nécessité d'intensifier les recherches visant à réduire cette pénibilité tout en identifiant les combinaisons optimales en matière d'allocation des ressources.

(Footnotes)

[1] Qui donne les rendements moyens de l'ensemble des techniques pour une culture données.

[2] 1 $ US = 500 FCFA

[3] Cité par S. Ouédraogo

[*] Le disponible céréalier tient compte des pertes et des besoins en semences (15%) et est évalué à 85 % de la production totale.

[4] Construction de l'auteur à partir des données du PS/CES-AGF

[5] INERA dans le cadre du programme RSP Centre (1993-1994)

[6] C.P : cordons pierreux

[7] Augmentation de 47% dans le cas du petit mil sous cordons pierreux

[8] Obtenue à partir de Faostat

[9] Augmentation de 11% pour le sorgho sous cordons pierreux

[10] Cité par S. Ouedraogo

[11] Augmentation de 47% dans le cas du petit mil sous cordons pierreux

[12] Obtenue à partir de Faostat

[13] Augmentation de 11% pour le sorgho sous cordons pierreux

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Chapter 14

Elevage et maintien de la fertilité des sols au Burkina Faso

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Résumé

Les systèmes d'élevage et d'agriculture au Burkina Faso déterminent, de manière simple ou complexe, la fertilité des sols. En zone semi-aride sahélienne, les indicateurs de fertilité définis comme étant les facteurs mesurables pouvant renseigner sur l'état de fertilité d'un sol sont la matière organique ou le carbone, l'azote, le phosphore, la production végétale ou production primaire (cultures et pâturages). La contribution des systèmes de production animale à la fertilité des sols est fonction des systèmes d'élevage qui sont variables selon les zones et les acteurs. Le système agro-pastoral correspond généralement au système mixte agriculture-élevage avec plusieurs variantes. Les modes d'élevage transhumant, semi-transhumant ou sédentaire se superposent souvent et déterminent également la contribution des productions animales en terme de quantité et qualité de matière organique disponible pouvant améliorer l'état de fertilité des sols. A l'échelle de l'exploitant, la quantité de fumier disponible est fonction de la taille du troupeau, du système d'élevage ou du mode d'alimentation adoptée. La quantité disponible pour fertiliser les champs est de 50% de la production estimée à 4.3 kg de fumier par tête de bovin et par nuit en saison des pluies et en moyenne 1.06 kg de fumier sec en saison sèche. Au niveau national, elle varie selon les étages bioclimatiques et les systèmes de production propres aux différentes régions. Annuellement, plus de 6 milliards de Tonnes de fumier sont produits au Burkina, représentant une capacité de fertilisation d'environ 500 000 ha de sols de cultures. Du point de vue de la qualité, ce sont les saisons, les types de pâturages, le régime alimentaire et les espèces qui sont les principaux facteurs déterminant les teneurs en nutriments du fumier. L'azote et le phosphore sont les éléments déterminants de la qualité de la fumure qui ont reçu le plus d'attention en termes d'études et d'analyse. Dans la province du Zoudweogo, le compost et le fumier des petits ruminants présentent des teneurs en azote variant entre 0.19 et 0.77% et entre 0.66 et 1.52% respectivement. Le fumier de volaille notamment celui des poules pondeuses est qualifié comme étant une source de nutriment organique très riche. Au Burkina Faso, les techniques d'amélioration de la qualité de la fumure sont variées : rotation céréales-légumineuses, enrichissement de l'alimentation du bétail par des intrants industriels et/ou l'utilisation d'un fourrage de meilleure qualité, mélange aux engrais à base de Burkina Phosphate dans les fosses compostières. L'utilisation efficiente de la fumure se fait traditionnellement par parcage du bétail sur les terres agricoles ou dans les enclos, ou par décomposition des ordures ménagers avec le fumier Les méthodes améliorées issues de la recherche sont les fosses fumières, le compostage en fosse avec finition en meule, le compostage aérobie et les parcs d'hivernage. Les interactions agriculture-élevage déterminent la fertilité des sols qui est fonction du cycle des nutriments et de la relation fumier-sol pour la décomposition du fumier dans le sol.

Mots clés: *Bétail, Burkina Faso, matière organique, qualité de fumier, fertilité des sols.*

Abstract

Livestock and agriculture systems determine soil fertility in a simple or complex way. In semi-arid zones, soil fertility indicators are defined as measurable factors that can inform on soil fertility status, such as organic matter or soil carbon, nitrogen and phosphorus content, and the primary productions (crops and pastures). The contribution of the animal production systems to the soil fertility is function of the raising systems that is variable according to the zones and the actors. The agro-pastoral system generally corresponds to agriculture-raising hybrid system with several variants. Usually, cattle raising types (transhumant, semi-transhumant or sedentary) are cross cutting themselves and determine the animal productions contribution in term of organic matter quantity and quality availability to improve the state of soil fertility. At the farmer scale, the quantity of available manure is function of the herd's size, the raising or the mode of feeding. The available quantity of manure for field fertilisation is about 50% of the quantity produced estimated to 4.3 kg per animal and per night during the raining season of and 1.06 kg of dry manure in the dry season. At the national level, it varies according to the bioclimatic zones and the systems of production. Annually, more than 6 billions of Tons of manure are produced in Burkina Faso, representing a soil fertilization capacity of about 500 000 ha of cropping soils. Manure quality is function of the seasons, the grazing systems, feeding modes and the animal. Nitrogen and phosphorus are the principal elements determining manure quality and receiving more attention in terms of study and analysis. In the province of the Zoudweogo, nitrogen content of goat/sheets compost and manure varies respectively from 0.19 to 0.77% and from 0.66 to 1.52%. The poultry manure is also qualified as a source of very rich organic nutrient content. In Burkina, there are many techniques of manure quality improvement: cereals-legume rotation, animal feeding enrichment by industrial inputs and/or use of a better quality fodder, Burkina Rocks Phosphate mixture with manure. Traditionally, manure use efficiency is better with corralling system (keeping animal on the fields during nights or in enclosures), or decomposition of domestic garbage with manure (tampouré). The improved methods from the research are the manure pits, the compost, anerobic compost and corralling. Crops-livestock interactions determine soils fertility that is function of the cycle of the nutriments and manure-soil relation for the decomposition of manure.

Key words: *Livestock, manure quality, organic matter, soil fertility, Burkina Faso*

Introduction

Le Burkina Faso est un pays dont l'économie repose en grande partie sur l'agriculture et l'élevage. Le secteur primaire (agriculture, élevage pêche et forêts) contribue pour environ 40% au PIB et procure près de 80% des recettes d'exportation (BAD/OCDE, 2003). Ces dernières décennies, le pays a connu des sécheresses plus ou moins importantes et un accroissement démographique crescendo de sa population. Il en résulte une forte pression agricole, une diminution progressive des terres agricoles, une surexploitation des ressources pastorales et une baisse des revenus qui ne permet pas des investissements en termes d'apport de fertilisants pour compenser les exportations minières du sol liées à l'agriculture. A cela, il faut ajouter la dégradation des terres du fait de l'érosion (éolienne ou hydrique), et des pratiques anthropiques telles que la réduction du temps de jachère, l'exploitation des forêts pour l'énergie domestique qui épuisent ces terres. La réduction du temps de jachère ne permet plus une reconstitution naturelle convenable du sol et les défrichements (dénudation totale du sol) pratiqués conduisent à une baisse de la teneur en matière organique du sol.

La dégradation des terres dans les zones de l'Est et de l'Ouest du Burkina Faso est fortement influencée aussi bien par l'élevage que l'agriculture comme on peut l'observer sur les figures 1 et 2 (Sawadogo et al. 2005). Le fort potentiel agronomique de ces terres en est la principale raison.

Des aménagements ont été mis en œuvre par les agriculteurs, sous l'impulsion des services techniques agricoles appuyés par la recherche, afin de réduire ou de minimiser l'effet de l'érosion sur les terres agricoles et améliorer la fertilité des sols. Ainsi, plusieurs options technologiques ont été proposées pour le maintien ou l'amélioration de la fertilité des sols (Ouédraogo, 2005).

Parmi elles, on note l'utilisation (l'enfouissement) des résidus de récoltes, l'utilisation d'engrais minéraux et organiques (principalement la fumure). L'utilisation de la fumure organique met, de ce fait, à contribution la production animale.

L'objectif du présent chapitre est de faire une revue scientifique de la contribution de l'élevage en matière de fertilité des sols notamment dans le cadre de l'intégration l'agriculture[1] - élevage au Burkina Faso. Les interactions agriculture-élevage se traduisent par les relations sol-plante-animal dans des systèmes d'exploitations intégrées ou non ayant des effets plus ou moins positifs sur la fertilité des sols.

Le terme agriculture ici n'est pas pris dans son sens large tel que donné, par exemple, par le dictionnaire *Larousse* qui le définit en ces termes : *''activité économique ayant pour objet la transformation et la mise en valeur du milieu naturel afin d'obtenir les produits végétaux et animaux utiles à l'homme, en particulier ceux destinés à son alimentation''*. Nous utiliserons durant tout le texte le terme agriculture en référence uniquement à la production végétale

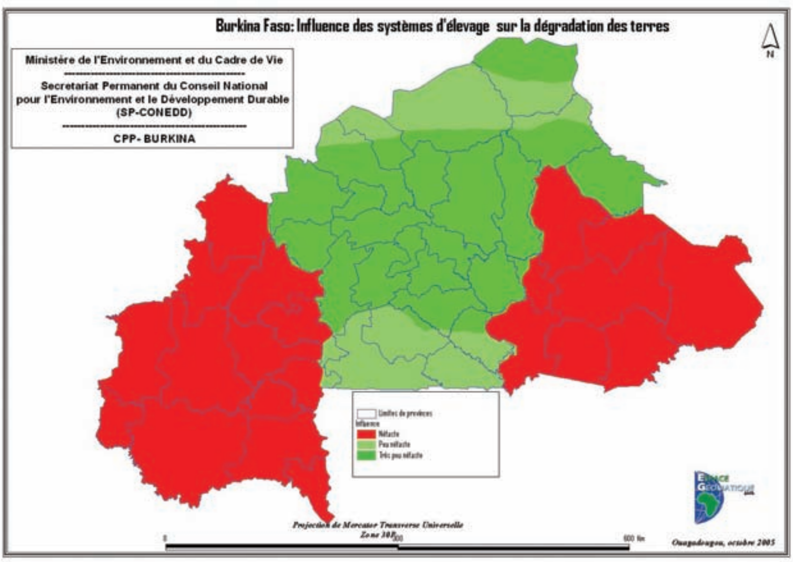

Figure 1: Niveau d'influence des systèmes d'élevage sur la dégradation des terres au Burkina Faso (CPP Burkina , Espace Géomatique, 2005)

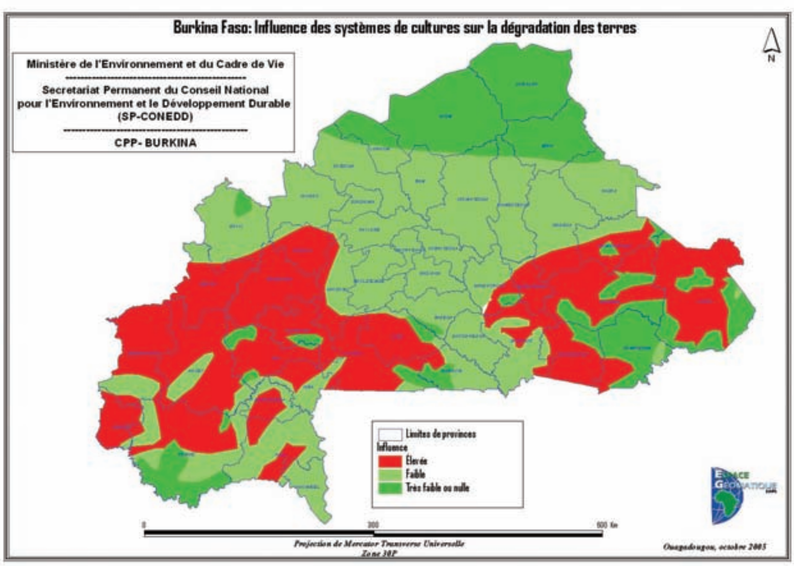

Figure 2: Niveau d'influence des systèmes de culture sur la dégradation des terres au Burkina Faso (CPP Burkina , Espace Géomatique, 2005).

Les principaux indicateurs de fertilité des sols en zone semi-aride sahélienne

Les indicateurs de fertilité désignent ici les facteurs mesurables pouvant renseigner sur l'état de fertilité d'un sol notamment la matière organique ou le carbone, l'azote, le phosphore, la production végétale et de manière indirecte la production animale notamment la production secondaire (viande ou lait) du milieu par rapport à la production primaire (pâturages).

La matière organique

Dans les systèmes de production mixte de l'Afrique sub-sahélienne, où se superposent accroissement de population, surexploitation agricole des terres et pauvreté, la matière organique constitue un élément clé dans la gestion de la fertilité des sols. Selon Bationo et al. (2004), elle agit comme une source ou un réservoir de nutriments pour la plante. Les autres gains importants résultants du maintien de la matière organique sont la rétention, le stockage des nutriments, augmentant ainsi la capacité de rétention d'eau.

L'azote

L'azote est un élément clé de la fumure organique et de l'état de la fertilité du sol. Sa contribution issue de la décomposition du fumier au niveau des cultures est très importante dans les systèmes agropastoraux. En Afrique centrale et du Sud, elle est estimée à environ 80% du N total (Kithanda 1996; Mugwira et Murwira 1997).

L'azote du sol provient de l'air et de la poussière, de la fixation biologique de l'azote par les plantes, des ''sources'' organiques et des fertilisants (Bationo et al. 2004), L'azote total dans le sol et l'azote assimilé par les plantes dépendent de la teneur en matière organique, dans la mesure où près de 98 % de l'azote du sol est sous forme de matière organique. C'est par minéralisation que la matière organique du sol libère l'azote utilisable par les plantes (Bado 2002). Cette minéralisation de la matière organique est plus rapide sous climat tropical semi aride chaud.

D'après Murwira et al. (1995), la minéralisation de l'azote est plus rapide et les pertes par volatilisation (sous forme d'ammonium) sont plus importantes au niveau des déjections animales qu'au niveau de la litière des plantes, même si les nutriments contenus dans le fumier sont dans une forme plus facilement utilisable pour la plante.

Pour Bationo & Vlek (1998) in Bationo et *al*. (2004), la rotation des céréales avec les légumineuses serait un moyen d'augmenter la teneur en azote du sol. Dans ce sens, selon les conclusions de Bado (2002), comparativement à une culture non fixatrice d'azote comme le sorgho, par exemple, qui utilise uniquement l'azote du sol, l'arachide et le niébé prélevent à hauteur de 17 à 56 % leur azote dans l'atmosphère, ce qui montre que les légumineuses augmentent la nutrition en azote.

Le carbone

Les sols de la zone soudano-sahélienne sont fondamentalement pauvres en carbone d'origine organique. Ceci est dû au faible développement racinaire des cultures et de la végétation naturelle, mais aussi à la dégradation rapide des matériaux organiques sous l'action de la forte température des sols et de la microfaune en particulier les termites (Bationo et al. 2004).

Le phosphore

Le phosphore a une importance relativement moindre par rapport à l'azote mais elle joue aussi un rôle non moins important dans la fertilisation du sol. L'un des effets de l'enrichissement du sol par la fumure est l'augmentation du phosphore dans le sol (Powell & Williams 1995). Ce qui est important pour les sols Ouest Africains de la zone semi aride qui sont plus déficients en phosphore qu'en azote.

La production végétale

La production végétale est un bon indicateur de l'état de fertilité d'un sol si on se base sur le simple fait que la plante tire une bonne partie de ses ressources du sol. Cependant, pour des analyses plus poussées, un poids ″fertilité″ reste à définir pour la fonction ″production végétale″ afin de déterminer l'impact de la fertilité du sol sur la croissance et le développement de la plante.

Dans tous les cas, il faudrait distinguer les intrants (fertilisants), la fumure organique et la fumure minérale (NPK, urée et autres engrais industriels), et souligner l'importance de l'eau (de pluie ou d'irrigation) pour la plante.

La production animale

Dans les systèmes de production extensive ou mixte, la production animale renseigne sur l'état de la fertilité des sols à travers la qualité (et même la quantité) de la production végétale dans la mesure où cette production végétale sert de base alimentaire au bétail. Cependant, cette influence doit être nuancée car de plus en plus, les éleveurs ont recours à des intrants externes pour l'alimentation du bétail, comme les graines de coton, les sons et les mélasses dans les techniques d'embouche. Dès lors, on n'a pas une relation symétrique entre production animale et production végétale; la relation directe de cause à effet entre bonne production végétale (résultant d'une bonne fertilité des sols) et bonne production animale est donc à nuancer.

Contribution des systèmes de production animale à la fertilité des sols au Burkina Faso

Systèmes d'élevage au Burkina Faso

La figure 3 montre la répartition spatiale des systèmes d'élevage au Burkina Faso et la figure 4 décrit les systèmes de cultures. Dans le système agro-pastoral correspondant généralement au système mixte agriculture-élevage, on distingue plusieurs variantes : petits ruminants + animaux de traits, gros ruminants + animaux de trait ou petit élevage villageois, gros ruminants, gros + petits ruminants. Dans ce système, le mode d'élevage peut être transhumant ou sédentaire. Dans le système pastoral, le mode d'élevage est transhumant, semi-transhumant ou sédentaire. Dans ce système, toutes les espèces sont concernées (gros et petits ruminants, petit élevage).

Ces systèmes d'élevage qui se superposent souvent, déterminent les productions animales dont la contribution à la fertilité des sols est fonction des systèmes de production. Ceux-ci déterminent en effet, la qualité et la quantité de matière organique disponible pouvant améliorer l'état de fertilité des sols.

Slingerland (2000) a identifié 4 systèmes de production au Burkina Faso:

- le système spécialisé en production animale ou en production végétale, chacun à faible utilisation d'intrants;
- le système intégré;
- le système mixte avec ou sans utilisation d'intrants;
- le système spécialisé basé sur l'utilisation d'intrants.

Ces systèmes vont des plus simples aux plus complexes. Pour un exploitant, la migration d'un système de production vers un autre est en général motivée, soit par des contraintes, soit par le désir d'intensification de son activité. Les contraintes sont en général liées à la baisse de fertilité des sols et/ou l'impossibilité d'extension des terres cultivables, causée par l'augmentation de la densité démographique.

Les *systèmes spécialisés* avec utilisation d'intrants au Burkina Faso ne sont pas très courants. Dans ces systèmes, l'accent est mis sur un produit, utilisant tous les intrants pour une maximisation de ladite production **(**Slingerland 2000**)**. La production de coton en est l'exemple par excellence. Les producteurs de coton se servent des bovins pour le labour et la production de fumier, sans pour autant s'investir dans la production animale. Néanmoins, ils achètent de plus en plus d'animaux comme forme d'épargne mais en gestion extensive..

L'intensification d'un système de production végétale vise l'amélioration des rendements de culture, qui passe par un apport d'intrants ou une augmentation des terres cultivées (incluant les jachères et autres terres de pâturage disponibles). Dans tous les cas, la fumure organique a un grand rôle à jouer. Mais, le faible pouvoir d'achat de la plupart des agriculteurs et éleveurs burkinabé et les difficultés d'accès aux intrants industriels, dus à la pauvreté, ont imposé la migration du système simple spécialisé en production animale ou végétale vers le système intégré.

Le *système intégré de production* combine l'agriculture et l'élevage en vue d'une amélioration des productions et on y observe des apports mutuels entre agriculteurs et éleveurs. Les systèmes intégrés de production, bien qu'ils soient assez répandus au Burkina Faso, ne sont pas pratiqués de la même façon d'une région à une autre, les pratiques culturales étant tout aussi différentes. D'après Savadogo (2000), les résidus de culture jouent un rôle clé dans un système de production intégré. Ils peuvent être laissés sur le champs ou pâturés par le bétail, travaillés (enfouis, par exemple) ou brûlés ou collectés pour l'alimentation du bétail de ferme. Dans tous les cas, ils sont une source de nutriments (quand ils sont décomposés) et/ou de matière organique (quand ils résistent à la décomposition), soit directement, soit sous la forme de fumier. Cependant, dans le cadre de la fertilisation/restauration des sols, ils peuvent mettre en concurrence l'agriculture et l'élevage : protection des sols contre alimentation du bétail surtout en saison sèche. Mais cette ''concurrence'' pour les résidus de culture peut être, en général, résolue par les agriculteurs suivant le système de production agricole adopté.

Il faut mentionner que le principal élément de concurrence entre agriculture et élevage se situe surtout au niveau spatial lorsque l'augmentation des superficies emblavées se fait au détriment des espaces pâturables notamment dans les zones à faibles rendements agricoles.

Les *systèmes mixtes de production* des zones semi-arides de l'Afrique de l'Ouest sont basés sur le recyclage des éléments nutritifs à support organique en vue du maintien de la productivité des sols (Somda et al. 1995). En effet, de par le passé, pour pallier aux problèmes de fertilité des sols, les cultivateurs avaient l'habitude de passer des ''contrats'' de parcage avec les éleveurs transhumants de gros bétail (bovins) pour la fourniture de fumier (recherche de fertilisants organiques). Ce type de contrats avaient lieu pendant la saison sèche et s'exécutaient de manière rotative, dans les champs pendant 4 à 6 semaines. Mais ce système a montré ses limites car la dégradation de l'environnement et les sécheresses successives ont obligé de plus en plus les éleveurs à se sédentariser et à cultiver des céréales. L'offre de fumier aux cultivateurs et les contrats de fumure ont alors diminué (Songué 1997). La vaine pâture généralement pratiquée en toute saison limite aussi les quantités de fumier pouvant être collectée et utilisée de manière rationnelle

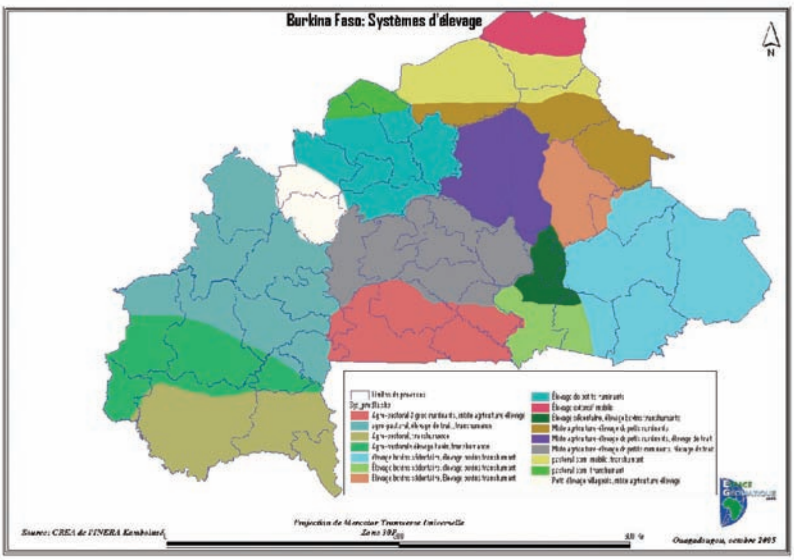

Figure 3: Les systèmes d'élevage du Burkina Faso (Srce : INERA, 1998)

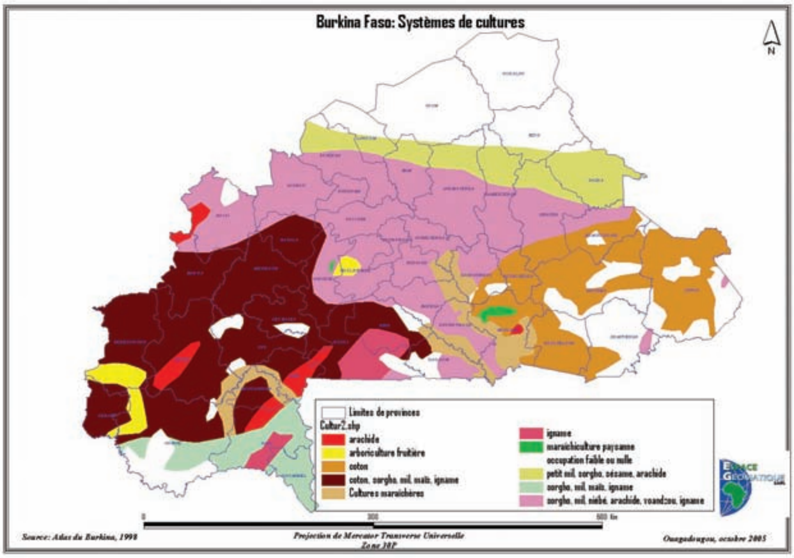

Figure 4: Les systèmes de culture du Burkina Faso (Srce : Atlas du Burkina. 1998)

La production de fumier et son influence sur la fertilité des sols au Burkina Faso

La quantité et la qualité de fumier produit à l'échelle nationale sont très variables suivant les étages bioclimatiques et les systèmes de production propres aux différentes régions. La typologie et les caractéristiques des producteurs pratiquant une activité d'élevage influent également le mode de transfert du fumier dans les champs (tableau 1).

A l'échelle de l'exploitant, *la quantité de fumier* disponible est fonction (hormis le facteur climatique) de la taille du troupeau, du système d'élevage (transhumant ou sédentaire) ou du mode d'alimentation adoptée (vaine pâture, alimentation à l'étable, apports de résidus de cultures et/ou d'intrants externes). Les quantités de fèces excrétées varient aussi assez fortement avec la saison (Landais et Lhoste, 2003.).

Il existe tout de même une différence entre les quantités réellement produites et celles qui peuvent être comptabilisées dans la fertilisation des terres cultivées étant donné que les déjections laissées dans la nature ou sur les terres de pâturage et de parcours sont difficilement chiffrables.

Songué (1997), dans son modèle d'intégration élevage-agriculture, a montré que la production de fumure de l'UBT (unité de bétail tropical, d'un poids standard de *250* kg vifs qui ingère environ *2*300 kg de MS/an soit *6,25* kg par jour) pouvait atteindre 1 tonne par an. Les travaux de Miedema (1994) sur la production du fumier dans le Zoundwéogo ont montré des productions de 4.3 kg de fumier par tête de bovin et par nuit en saison des pluies tandis qu'en saison sèche, la moyenne est de 1.06 kg de

Tableau 1: Mode de transfert de fumier selon la typologie et caractéristiques majeures des producteurs pratiquant une activité d'élevage (Source. Etude IEPC/ MRA, 2004)

Producteurs	Systèmes d'élevage	Zonage	Main d'oeuvre	Mobilité	Equipement	Transfert de fumure
1. AGRO PASTEURS						
Agro pasteurs à transhumance de petite envergure (zone sahélienne)	Bovin à transhumance de petite envergure Atelier laitier sédentaire Ovin transhumant. avec atelier d'embouche Caprin sédentaire (race du Sahel) Avicole villageois, poules	Point d'attache en zone sahélienne	Familiale + bergers salariés (éventuellement communautaires)	Petite tr. de SH[1] pour s'éloigner des zones de culture Tr. de SS de petite envergure, (regroupement autour des points d'eau permanent)		Parcage sur les champs
Agro pasteurs à transhumance de petite envergure (zone soudanienne)	Bovin transhumant petite envergure. Atelier laitier et bovin de trait Ovin sédentaire. (ace du Sahel) avec atelier d'embouche Caprin sédentaire (race du Sahel) Avicole villageois, poules	Point d'attache en zone soudanienne	Main d'oeuvre familiale	Petite transhumance. de SH vers les collines. Transhumance . de SS de petite envergure, (vers les fleuves et autres points d'eau)	Présence et développement de traction attelée	Transfert de fumure de parc, dont une partie au profit des propriétaires de charrettes
Agro pasteurs à transhumance de grande envergure	Bovin à transhumant de grande envergure, avec atelier laitier sédentaire et boeuf de trait Ovin transhumant Caprin sédentaire, race du Sahel Avicole villageois, poules	Zone sahélienne et ménages implantés en zone soudanienne (Est et Ouest)	Familiale avec recours à de la main d'œuvre salariée souvent pratiqué	Petite transhumance. de SH vers les collines. Transhumance. de SS de grande envergure, souvent transfrontalière	Présence et développement de traction attelée	Parcage sur les champs, limité au noyau d'élevage et éventuellement à quelques mois pour le troupeau transhumant.
Agro pasteurs s'occupant notamment d'animaux confiés	Bovin sédentaire Ovin sédentaire, race du Sahel avec atelier d'embouche Caprin sédentaire, race du Sahel - Avicole villageois, poules	Le plus fréquents dans le plateau central et les régions de l'Ouest.	Main d'oeuvre familiale	transhumance. de petite envergure en zones denses	-	

[1] *SH: Saison humide; SS: Saison sèche.*

Producteurs	Systémesw d'élevage	Zonage	Main d'oeuvre	Mobilité	Equipement	Tranfert de fumure
	Avicole villageois, poules					
Agro pasteurs s'occupant notamment d'animaux confiés	Bovin sédentaire Ovin sédentaire, race du Sahel avec atelier d'embouche Caprin sédentaire, race du Sahel - Avicole villageois, poules	Le plus fréquents dans le plateau central et les régions de l'Ouest.	Main d'oeuvre familiale	transhumance. de petite envergure en zones denses	-	
2. AGRO ELEVEURS EN SITUATION PRECAIRE						
Agro éleveurs à cultures vivrières et petit élevage bovin	Bovin sédentaire Ovin sédentaire, race du Sahel ou Mossi avec atelier d'embouche Caprin sédentaire, race du Sahel ou Mossi Avicole villageois, poules, (pintades)	Fréquents dans le plateau central mais, présents dans toutes les régions	Main d'oeuvre familiale avec parfois recours au confiage des bovins	Elevage sédentaire (sauf parfois troupeaux mobilité des ovins)	Parfois traction attelée asine	
Agro éleveurs à cultures vivrières et élevage de volailles	Avicole villageois, poules et pintades	Présents et très fréquents dans tout le territoire, surtout dans les régions du centre et en zones «denses» (sauf les agro éleveurs avec élevage de porcins (localisés principalement dans l'ouest)	Main d'oeuvre familiale et activités d'élevage le plus souvent sous la responsabilité des femmes (porcins en particulier)			
Agro éleveurs à cultures vivrières et élevage de petits ruminants	Ovin sédentaire. race Mossi ou Peul avec atelier d'embouche Caprin sédentaire, race Mossi ou Peul Avicole villageois, poules et pintades					
Agro éleveurs à cultures vivrières et élevage de porcins	Ovin sédentaire, race Mossi avec atelier d'embouche ovine - Caprin sédentaire, race Mossi - Porcin villageois Avicole villageois, poules et pintades					
3. AGRO ELEVEURS EN VOIE D'INTEGRATION / D'ACCUMULATION						
Agroéleveurs à troupeau bovin et cultures de rente	Bovin sédentaire avec atelier de trait Ovin sédentaire race Mossi avec atelier d'embouche Caprin sédentaire, race Mossi Avicole villageois, poules et pintades	Surtout présents dans les zones à forte emprise agricole (anciennes et récentes)	Main d'œuvre familiale et souvent recours aux salariés agricoles (bergers – confiage des bovins). Activités d'élevage largement prises en charge par les enfants et les femmes	Elevage généralement sédentaire avec tr de petite envergure en zones denses	Traction attelée, plusieurs attelages, charrette (tracteur)	

Producteurs	Systémesw d'élevage	Zonage	Main d'oeuvre	Mobilité	Equipement	Tranfert de fumure
Agroéleveurs à traction attelée bovine	Atelier de trait Ovin sédentaire. race Mossi avec atelier d'embouche Caprin sédentaire, race Mossi Avicole villageois, poules et pintades			Elevage sédentaire	Traction attelée bovine	Transfert fumure de parc Equipement en fosses fumières en cours
4. LES SYSTEMES INTENSIFIES / SPECIALISES						
Propriétaires de bétail confié	Bovin transhumant de petite envergure	Périurbain ou à proximité du village d'origine des propriétaires ou des villes dans lesquelles les propriétaires ont effectué une partie de leur carrière	Confiage à des bergers salariés payés en nature ou en espèces	Transhumance de petite et de grande envergure (lorsque la taille des troupeaux l'exige)	-	-
Eleveurs urbains laitiers	Bovin sédentaire, Zébus Atelier d'élevage urbain laitier	urbain / périurbain autour des grandes villes et de la plupart des villes secondaires	Groupements de femmes qui assurent également la transformation et / ou la commercialisation du lait	Elevage sédentaire	(Hangar)	(Vente de fumure)
Commerçants emboucheurs	Bovin ou ovin d'embouche	Autour des principaux centres de commercialisation en expansion.	Salariés	Elevage sédentaire	(Hangar)	(Vente de fumure ou transfert si activité agricole)
Propriétaires urbains à élevage moderne d'aviculture	Avicole intensif, poules pondeuses			Elevage sédentaire périurbain	Bâtiments d'élevage	Vente de fumure (parfois – en développement)
Propriétaires urbains à élevage moderne laitier	Bovin semi-intensif laitier					
Propriétaires urbains à élevage moderne porcicole	Porcin intensif					

fumier sec, ce correspond également des quantités moyennes de fumier sec de l'ordre de la tonne par an pour les bovins. Les quantités de fumier produit sont aussi liées à l'état de la production primaire (pâturages). Plus les pâturages sont abondants et de bonne qualité, plus le fumier est abondant et de bonne qualité. En effet, le recyclage des nutriments du sol par les déjections animales dépend, en premier lieu, de la richesse en éléments biogènes du fourrage consommé, mais aussi de l'espèce animale qui utilise ce fourrage. Somda et al. (1995) ont montré que le passage de la biomasse végétale à travers l'appareil digestif des ruminants joue un rôle primordial dans la régulation des processus de recyclage des éléments nutritifs en zone semi aride.

Le tableau 2 présente les quantités de fumier des ruminants en considérant 1 tonne /an/UBT pour les grands ruminants bovins et 0.7t/an/UBT pour les petits ruminants. Les quantités de fumier provenant des bovins sont de l'ordre de 3,5 Milliards de tonne et 1,4 Milliard environ pour les petits ruminants.

A ces quantités de fumier, il faut ajouter les fientes de volaille qui constituent un stock de matière organique. En effet, l'aviculture villageoise est très développée au Burkina Faso et l'aviculture intensive (poulets de chair et pondeuses) est en pleine expansion notamment dans les centres urbains. Les fientes issues de ces élevages constituent des apports non négligeables de fumier pour les champs de case (jardins potagers et maïs de case). Des recherches spécifiques au Burkina Faso ne sont pas encore faites sur les quantités de fientes produites. La littérature sur le sujet avance des chiffres moyens de 60 kg de fientes par an pour les poulets de chair et les pondeuses. Cependant, il est à noter que les volailles élevées traditionnellement (poules, pintades, dindons, canards) produisent beaucoup moins de fientes étant donné le niveau de l'alimentation

En considérant une production moyenne de 40 Kg de fientes par an et par volaille, la production moyenne de fientes de volailles au Burkina pourrait être évaluée en 2004 à environ 1 200 Tonnes de fientes (tableau 3).

Le transfert du fumier dans les champs est fonction du système d'élevage mais aussi dépend des zones agro écologiques comme le montre le tableau 1. L'observation de ce tableau montre qu'en zone sahélienne, les agro pasteurs transfèrent directement le fumier par parcage dans les champs alors qu'en zone soudanienne, le transfert se fait à partir de l'enclos pour l'élevage sédentaire et par parcage au champ des animaux transhumants. Les quantités récupérées annuellement ne dépassent guère 300 à 500 kg (Songué (1997), soit la moitié ou même le tiers de la production. Les quantités comptabilisées correspondent principalement à la production nocturne des animaux enfermés dans les enclos, la production dans la journée étant éparpillée dans les pâturages et pas récupérée.

En considérant les effectifs du cheptel Burkinabe et un taux de transfert du fumier des ruminants au champ de 50% et des apports de 5T de fumure organique à l'hectare, environ 500 000 ha de sols de cultures ont été fertilisés en 2001 grâce à l'élevage, ce qui représente 1/5 des terres emblavées. Ces apports suivent l'accroissement du cheptel. Par exemple en 2004, les productions de fumier provenant des ruminants étaient estimés à environ 6 millions de tonnes inégalement réparties selon les régions en fonction des systèmes d'élevage pratiqués (tableau 4) soit 3 Millions (50%) de tonnes de fumier transféré dans les champs.

Tableau 2: Production de fumier en 2001 selon les systèmes d'élevage

Systèmes d'élevage	Effectifs	Equivalent UBT	UBT Total	Fumier (1T/an/UBT)
Bovins				
Bovin à transhumance de grande envergure	1 542 000	0.70	1 079 400	1 079 400
Bovin à transhumance de petite envergure	1 542 000	0.70	1 079 400	1 079 400
Bovin sédentaire (zébu peul)	660 000	0.70	462 000	462 000
Bovin - Embouche familiale	44 000	0.70	30 800	30 800
Bovin - Embouche commerciale	88 000	1.00	88 000	88 000
Bœufs de traction	528 000	0.70	369 600	369 600
Bovin sédentaire (taurins)	465 000	0.70	325 500	325 500
Bovin laitier semi-intensif (zébu peul)		1.00	-	-
Bovin laitier semi-intensif (métis)	24 000	1.00	24 000	24 000
Ss/Total	***4 893 000***		***3 458 700***	***3 458 700***
Ovins				
Ovin transhumant (race sahel)	2 270 000	0.10	227 000	227 000
Ovin sédentaire (race sahel)	1 816 000	0.10	181 600	181 600
Ovin - Embouche familiale	227 000	0.10	22 700	22 700
Ovin - Embouche commerciale	227 000	0.10	22 700	22 700
Ovin sédentaire (race mossi)	2 445 000	0.10	244 500	244 500
Ss/Total	***6 985 000***		**698 500**	**698 500**
Caprins				
Caprin transhumant (race sahel)	2 316 000	0.08	185 280	185 280
Caprin sédentaire (race sahel)	3 476 000	0.08	278 080	278 080
Caprin sédentaire (race mossi)	3 117 000	0.08	249 360	249 360
Ss/Total	***8 900 000***		***712 720***	***712 720***
				4 869 920

Tableau 3: Effectifs de volaille et quantité de fiente produite en 2004 au Burkina Faso

Espèce	**Nbre**	**Quantité de fientes**
Poules*	24 508 506	980 340
Pintades	6 117 826	244 713
Dindons	43 521	1 741
Canards	211 828	8 473
Pigeons	1 183 385	47 335
TOTAL		**1 282 603**

Qualité de la fumure organique

Parmi les éléments déterminants de la qualité de la fumure, l'azote et le phosphore ont reçu le plus d'attention en termes d'études et d'analyse. L'azote favorise l'utilisation des hydrates de carbone, stimule le développement et l'activité racinaire, favorisant ainsi l'absorption des autres éléments minéraux et la croissance des plantes (Stevenson 1986).

Tableau 4: Production de fumier en 2004 de ruminants selon les régions du Burkina

Région	**Effectifs en UBT**					**Production de fumier en T/an**	
	Bovins	**Ovins**	**Caprins**	**Equins**	**Asins**	**Bovins**	**Petits ruminants**
CENTRE	87743	16187	12949	1404	23741	87 743	20 395
CENTRE-SUD	179052	28862	23090	762	34094	179 052	36 367
PLATEAU - CENTRAL	182 452	41689	33351	1776	46154	182 452	52 528
SUD-OUEST	193182	19348	15478	424	1066	193 182	24 378
NORD	233603	66521	53217	7388	46172	233 603	83 816
CENTRE-EST	240265	52833	42267	2152	38247	240 265	66 570
CENTRE-NORD	288210	74167	59334	3780	29623	288 210	93 450
CASCADES	380794	17054	13643	90	829	380 794	21 488
CENTRE-OUEST	397413	74521	59616	376	61249	397 413	93 896
BOUCLE du MOUHOUN	451907	55010	44008	2410	57141	451 907	69 312
EST	581863	68624	54899	4430	46604	581 863	86 466
HAUTS-BASSINS	849824	61437	49150	508	40296	849 824	77 411
SAHEL	1051774	94013	75210	10567	32060	1 051 774	118 456
TOTAL	**5 118 081**	**670 264**	**536 211**	**36 067**	**457 272**	**5 118 081**	**844 533**

On note cependant une grande diversité qualitative mais aussi une imprécision dans la terminologie des produits utilisés en fumure organique animale (Milieville, 1986) : fumier, terre de parc, poudrette, compost, etc. Les tableaux 5 et 6 présentent la composition minérale de ces différents produits selon Quilfen et Milleville (1983).

Slingerland & Savadogo (2000) ont noté des teneurs en azote variant entre 0.19 et 0.77% et entre 0.66 et 1.52% pour, respectivement, le compost et le fumier des petits ruminants dans la province du Zoudweogo.

Tableau 5: Comparaison de la teneur minérale du fumier (% de la MS) selon les produits

Fumiers	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Humidité (%)	-	-	-	21,1	57,4	66,2	37,4
N	2,47	1,44	0,89	1,50	1,45	1,28	0,72
P_2O_5	0,51	0,80	0,30	0,50	0,45	0,40	0,29
K_2O	4,26	0,70	0,30	2,48	2,02	1,19	0,85
CaO	1,00	1,37*	0,73*	1,43	1,29	0,87	0,62
MgO	0,67			1,22	0,36	0,58	0,46
Na	0,25						
Cendres	37,90	10,80	49,60	15,90	54,00	60,30	86,80
Cendres insolubles	18,50	5,40	45,70	7,40	47,30	55,40	82,50

Tableau 6: Variabilité de la composition minérale des terres de parc

Terre de Parc	**N (%)**	**P_2O_5 (%)**	**K_2O (%)**	**Ca**
Terre de parc sans paille (Mali)	1,30	1,50	2,46	-
Déjections termites après 45 j (Sénégal)	0,89	0,68	0,36	73 meq
Terre de parc (Burkina Faso)	1,28	0,57	0,67	-
Terre de parc (Cote d Ivoire)	1,50	0,59	1,08	0,5%
Terre de parc (Cote d Ivoire)	2,23	0,82	3,71	-
Bouses fraîches (Sénégal)	1,44	1,82	0,84	Ca + Mg 1,37 meq

L'azote se retrouve aussi bien dans les déchets fécaux que dans les urines tandis que le phosphore, en général, se retrouve uniquement dans les déchets fécaux. (Powell & Williams, 1995). Du point de vue de la répartition spatiale des éléments au niveau des fèces sur le sol, les couches supérieures sont plus riches en éléments fertilisants (N, P, K, Ca, Mg) et en matière organique, alors que la couche inférieure souillée par la terre est très riche en silice (cendres insolubles). Ces taux sont très affectés par le régime alimentaire, qui varie avec la saison en fonction des changements dans la qualité et l'accès au fourrage. Guar et *al*. (1985) ont montré que la teneur en phosphore dans le fumier dépend du régime alimentaire de l'animal, du mode de pâture. Ainsi, les nutriments contenus dans le fumier des bovins bien alimentés sont 3 fois plus élevés pendant la saison des pluies et post-récolte que pendant la saison sèche.

Ces variations sont aussi fonction des espèces. Powell & Williams (1995) ont montré que les teneurs en phosphore et en azote du fumier des petits ruminants et spécialement des caprins sont relativement plus élevées que celui des bovins. Au Nord du Burkina Faso, des travaux similaires de Quilfen et Milleville (1983) ont également montré que le taux de matière azotée était plus élevé dans les fèces des petits ruminants par rapport à celles des bovins (tableau 7).

Le temps de dépôt détermine aussi la qualité des fèces. Les dépôts frais sont plus riches en éléments minéraux que les dépôts anciens, en raison notamment de l'action des termites (Landais et Lhoste1993).

Tableau 7: Composition de fèces desséchées (saison sèche) sur le sol au Burkina Faso (Quilfen et Milleville, 1983)

Fèces	N (%)	P_2O_5 (%)	K_2O (%)
Fèces bovins	1,28	0,25	0,56
Fèces petits ruminants	2,20	0,27	0,88

Le fumier de volaille notamment celui des poules pondeuses est un produit relativement mature qualifié comme étant une source de nutriment organique très riche. Il a un taux de matière sèche relativement élevé et d'après sa composition chimique, il présente une concentration moyenne en azote, des concentrations élevées en phosphore et en potassium du fait du régime alimentaire fondé sur des grains de céréales. Ces éléments organiques sont à la base d'une fumure de qualité. L'azote contenu dans ce fumier n'est cependant pas disponible immédiatement pour la plante, il est progressivement libéré en petites quantités (effet à long terme). Néanmoins, à l'état frais, il peut présenter des risques potentiels de contamination de l'homme et des ruminants telle que la salmonellose du fait d'agents pathogènes pouvant être contenus dans les fientes (bactéries, parasites, virus)

Amélioration de la qualité de la fumure

Même si les engrais industriels constituent des intrants externes, pas toujours accessibles aux agriculteurs, il n'en demeure pas moins pour Bikienga (2002) que l'utilisation des engrais (en plus de la fumure organique) reste une solution efficace pour accroître les rendements des cultures et l'ensemble de la production agricole.

L'amélioration de la qualité du fumier se traduit par le niveau de ses éléments constitutifs notamment l'augmentation de la teneur en azote. Ainsi, sur le plan cultural, une rotation céréales-légumineuses permet un accroissement de l'azote et par suite, de l'azote dans les cultures et résidus de culture, les résidus de culture entrant en compte dans l'alimentation du bétail. Un des moyens d'amélioration de la qualité de la fumure peut être l'enrichissement de l'alimentation du bétail par des intrants industriels et/ou l'utilisation d'un fourrage de meilleure qualité.

Selon Fornage (1993, in Songué 1997), la qualité du fumier peut être améliorée en le mélangeant à des engrais à base de phosphate (200 kg de *Burkina Phosphate*, par exemple) dans une fosse compostière.

L'utilisation moyenne des fertilisants au Burkina Faso est seulement de 12 kg ha^{-1} de $N+P_2O_5+K_2O$, une valeur juste au-dessus de la moyenne africaine, mais qui ne représente que la dixième de la moyenne mondiale (Henao et Baanante 1999 in Breman 1999).

Utilisation efficiente de la fumure

Il existe deux principales méthodes traditionnelles d'application de la fumure en Afrique sub-saharienne :

1. le bétail est ''parqué'' sur les terres agricoles les nuits entre les saisons de culture et ainsi ces terres profitent directement des déjections animales;
2. le bétail est enfermé dans des enclos et le fumier y est collecté et répandu manuellement sur les terres agricoles .

Le parcage du bétail sur les terres agricoles procure à la terre aussi bien le fumier que les urines et résulte en de plus grandes superficies enrichies par rapport à un épandage manuel après collecte. En effet, 40 à 60% de l'azote excrété par les ruminants se trouve dans les urines (Powell & Williams 1995). Cette fraction est donc perdue pour l'agriculture quand le bétail est en enclos.

Une autre utilisation efficiente de la fumure organique consiste à synchroniser l'utilisation de la fumure avec la demande en nutriments de la plante. Selon Somda et al. (1995), l'application d'amendements organiques au sol de façon à ce que leur décomposition et leur absorption coïncident avec la demande en nutriments des cultures peut accroître l'efficacité du cycle des nutriments dans les systèmes à faible utilisation d'intrants externes. Ces auteurs ont montré que la minéralisation des nutriments contenus dans le fumier est plus rapide et apparaît plus synchronisée avec la demande en nutriments des plantes que la minéralisation des nutriments du fourrage et autres résidus de culture appliqués au sol.

La recherche a permis de développer des technologies permettant d'améliorer les savoirs faire des producteurs en matière d'utilisation efficiente du fumier en zone sub sahélienne notamment, le tampouré, la fosse fumière, le compostage en fosse avec finition en meule (Ouédraogo et Nikiéma ,1991; Sawadogo et al., 2005)

Le tampouré est une méthode traditionnelle qui consiste à rassembler les différentes ordures ménagères dans un lieu proche de la case. Les ordures sont laissées à ciel ouvert. La décomposition intervient surtout dans les parties inférieures. Les produits dérivés du tampouré sont utilisés comme fumure notamment pour les champs de case. Les principaux inconvénients du tampouré sont le manque de décomposition complète du matériau, notamment sa partie supérieure, son taux souvent élevé en cendre et de ce fait parfois néfaste pour les cultures et l'absence de proportions équilibrées des matériaux constitutifs. Il n'en demeure pas moins que la technique présente des avantages parmi lesquels on peut citer sa facilité de mise en œuvre, la valorisation des déchets ménagers et l'obtention d'une bonne fumure lorsque le tampouré est bien arrosé par les pluies.

La technique de la fosse fumière consiste à creuser un trou rectangulaire ou circulaire peu profond (moins de 2m) et à y jeter divers matériaux constitués de débris ménagers, d'herbes, de déjections animales. Tout le mélange est arrosé par les eaux de pluies pendant une année. Une autre variante de la fosse est le bassin de décomposition qui lui est construit sans creuser la terre, à partir de briques ou de pierres. Les principaux inconvénients de la technique sont la demande en main d'œuvre pour le creusage et le vidange de la fosse, la faible décomposition du matériau et l'appariation de toxines tel les nitrites pour les cultures, la fosse étant en mode anaérobie. Le principal avantage est qu'il ne demande pas d'effort dans son entretien et la fumure produite peut être de bonne qualité si les matériaux de base sont bien choisis.

Le compostage en fosse avec finition en meule se réalise à partir d'une fosse creusée ou d'un bassin, d'une étable et d'une meule. La fosse reçoit les déjections et urines produites à partir de l'étable où des matériaux végétaux et des cendres sont mélangés ou non. Par la suite, les produits sont conservés en mode aérobie dans la meule faite en paille et tiges. Les inconvénients liés à la technique sont essentiellement l'exigence en matériel de transport assez moderne (charrettes, fûts), l'éloignement des points d'eau pour l'arrosage, l'indisponibilité d'une main d'œuvre suffisante et de constituants. Ses avantages sont la production en quantité importante de fumure, l'amélioration de la qualité du produit en mode aérobie, une fumure bien décomposée, une intégration agriculture-élevage.

Le compostage aérobie ressemble à celle de la fosse fumière à la différence notable de la construction de plusieurs bacs, d'une combinaison bien étudiée de plusieurs couches de matériaux et un entretien de la fosse, par retournement régulier des matériaux. Une très bonne fumure est produite. Les inconvénients portent sur le matériel de transport, l'indisponibilité parfois des matériaux de compostage, la rigueur dans la disposition des matériaux et des dates de retournement. Les avantages sont multiples et comprennent la rapidité de la décomposition des matériaux, la bonne qualité de la fumure et l'utilisation possible du bassin de décomposition à d'autres fins.

Le parc d'hivernage consiste à disposer des résidus de récoltes ou des herbes dans les lieux de pacage des animaux. Ces lieux sont circonscrits et un mélange par les animaux en pacage a lieu entre la couche de débris déposés et leurs déjections. Les matériaux de base sont également broyés par les animaux à la suite de leurs piétinements. Dès la saison des pluies, les animaux sont déplacés et le parc est laissé arrosé par les eaux de pluies jusqu'au début de l'hivernage suivant. C'est alors que la fumure produite est utilisée dans les champs. Les inconvénients liés au parc d'hivernage sont l’exigence en bois pour la construction du parc, la nécessité d’avoir assez de tiges de résidus et d’animaux pour le parc. Les avantages sont que les apports de tiges sont faits progressivement, ce qui est léger pour le producteur, une bonne production de matière organique en quantité et en qualité, la simplicité de la technique.

Dans certaines régions du Burkina Faso telle que la province du Zoundwéogo, tous les agriculteurs utilisent du compost à base de fumier bovin et de petits ruminants, d’ordures ménagères et de cendres, avec un peu de résidus de culture (Slingerland & Savadogo 2000).

Les quantités typiques des couches 0-20 cm du sol du ranch sont indiqués dans les (P en kg ha^{-1} et celles des transformations dans les (en kg/ha/an).

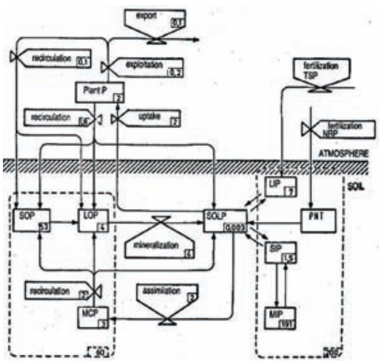

Figure 5 : Cycle du Phosphore d’après Penning De Vries et Djiteye (1982)

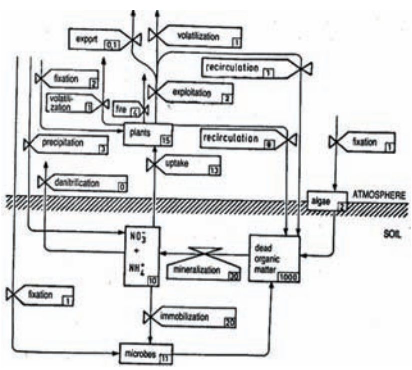

Figure 6 : Cycle de l’Azote d’après Penning De Vries et Djiteye (1982

Décomposition du fumier dans le sol (relation fumier-sol)

Les processus de décomposition du fumier dans le sol déterminent le taux de diffusion du carbone et des nutriments (contenus dans le fumier), l'équilibre entre pertes et rétention dans le sol. La plupart des études menées sur la décomposition du fumier se focalisent sur la dynamique de l'azote (N) dans la mesure où sa teneur initiale dans le fumier détermine le ''taux'' de minéralisation des nutriments sous la forme inorganique. La teneur initiale en azote est fortement influencée par les conditions de stockage du fumier avant son utilisation.

Pour établir la relation fumier-sol, les études quantitatives et qualitatives sur la transformation de l'azote dans le sol sont nécessaires. Elles permettent de déterminer notamment le temps de la transformation, le temps au bout duquel l'azote transformé est disponible pour la plante et la contribution du fumier apporté à l'azote du sol. L'azote du fumier est retenu sous forme organique dans le sol, ou est minéralisé dans le sol où il s'accumule et est utilisé par les plantes ou perdu par lessivation ou évaporation.

L'utilisation efficiente de l'azote dans le cadre de l'agriculture nécessite une utilisation optimale de l'azote par la plante et un maximum de rétention par le sol (Myers et *al*., 1994).

Powell et Williams (1995), en comparant les propriétés du sol des parcelles enrichies avec de la fumure, ont constaté que celle-ci augmentait le pH du sol ainsi que la matière organique, l'azote et le phosphore disponibles.

Les procédés de décomposition du fumier en éléments minéraux et en CO_2 sont relativement standard, avec quelques différences dues à la qualité du fumier. La qualité du fumier désigne les facteurs intrinsèques qui affectent la faculté de décomposition des lignines, des nutriments (en fonction de la taille de leurs particules) qui, avec les facteurs environnementaux, physico-chimiques et biologiques, régulent le processus de décomposition globale (Swift et al., (1979).

La minéralisation de l'azote est régulée de même par des facteurs tels que la température, l'humidité, le pH, les teneurs en lignine et polyphénol et le rapport C/N (carbone/azote). En outre, les taux et les procédures de décomposition et de minéralisation sont aussi influencés par le type de sol et les interactions avec les autres fertilisants et amendements du sol.

Relation sol-plante-animal

Observons à une échelle macroscopique le cycle des nutriments dans la nature, en partant de leur présence dans le sol. Schématiquement, les nutriments présents dans le sol sont, soit transformés en minéraux, soit évaporés sous forme de gaz, soit lessivés, soit utilisés/consommés par les plantes.

Intéressons nous ici à cette fraction des nutriments utilisée par les plantes : les nutriments contribueront à la croissance et au développement de ces plantes. Les plantes ou les produits de ces plantes seront de quelque manière que ce soit, totalement ou partiellement, consommés par les animaux ou le sol, ou alors détruits. Dans la fraction de végétaux consommée par les animaux se trouvent certains nutriments qui, après digestion et excrétion (par les animaux), se retrouvent contenus dans le fumier, qui est utilisé pour l'enrichissement des terres. Ainsi, on peut sommairement illustrer le cycle des nutriments dans la nature.

Dans le cas de l'azote, les restitutions au sol sont relativement faibles pour des fourrages pauvres (estimées à 50 p. 100 en moyenne pour les pâturages sahéliens, d'après Penning De Vries et Djiteye, 1982), mais peuvent excéder 100 p. 100 pour les fourrages riches, ou s'il existe un apport exogène d'azote. Il y a alors augmentation de la production végétale, du fait d'une plus grande disponibilité des éléments fertilisants, qui conduit à une amélioration de l'alimentation des animaux, et par conséquent, à des restitutions au sol plus importantes, d'où la «stimulation biologique» du système.

En pratique, cette stimulation trouve rapidement ses limites, notamment lorsque l'azote du sol constitue, à la base, un facteur limitant pour la production primaire (Breman et de Wit, 1983). Par ailleurs, une partie de l'azote prélevée par les animaux est rejetée dans l'urine et se volatilise sous forme d'ammoniac, notamment lorsque l'urine est évacuée à maintes reprises au même endroit (Stewart, 1970).

La qualité de l'aliment (qui, toutefois, n'est pas tributaire de la seule alimentation par les plantes et résidus de plantes) influence la qualité du fumier qui influence l'état de la fertilisation du sol, qui influence à son tour la production végétale. On est en présence d'un système dont les éléments sont totalement ou partiellement dépendants l'un de l'autre et qui implique qu'une bonne agriculture peut résulter en un bon élevage et vice versa dans les systèmes mixtes.

Intégration élevage-agriculture au Burkina Faso

De tout temps l'utilisation de la fumure organique a fait parti de la pratique de l'agriculture (James and Sharon, 1992). D'après Songué (1997), l'analyse des étapes de l'évolution des systèmes de production a montré que l'intégration élevage-agriculture a été perçue comme solution à l'augmentation de la densité de population qui ne permettait plus les longues jachères (10 à 20 ans), moyens faciles de régénération des sols. Dans les régions à dominance agricole (zone soudanienne), l'utilisation du gros bétail (bovin notamment) pour la fertilisation des terres cultivées, s'est accentué. En effet, du point de vue des cultivateurs, l'élevage (et son produit ou sous produit, le fumier) est apparu comme solution aux problèmes d'engrais et de fertilisation, de restauration des terres dégradées ou épuisées, dans les régions où l'agriculture et l'élevage sont possibles.

Un système intégré d'élevage et d'agriculture est un système dans lequel on favorise les interactions élevage–agriculture afin de parvenir à un système optimisé dans lequel on voudrait obtenir le meilleur de l'un et de l'autre, par l'un et par l'autre, et d'améliorer les revenus de l'exploitant. On a ainsi un système où le produit (ou sous produit) d'une activité sert d'intrant à l'autre et vice versa.

Schématiquement, on pourrait considérer l'exemple de ferme ou d'une exploitation dans laquelle les sols sont enrichis avec l'apport de la fumure organique obtenue à partir des déjections animales. D'un autre côté, certains produits (plantes fourragères, par exemple) ou sous produits (tiges, résidus de culture, etc.) de l'agriculture entrent dans l'alimentation des animaux de l'exploitation.

On distingue plusieurs types d'intégration élevage-agriculture parmi lesquels on peut citer le système mixte d'agriculture et d'élevage qui correspond à un système à intégration totale.

Selon Ramisch (2000), le modèle mixte comporte des systèmes où les agriculteurs indépendants, bénéficiant d'une solide sécurité foncière, possèdent et gèrent un cheptel dont la fonction est de développer un cycle, où les éléments nutritifs, tirés des cultures fourragères et des champs de brousse, retournent à la terre sous forme de fumier. Une intégration plus poussée des systèmes de culture et d'élevage augmente l'efficacité d'emploi des facteurs de production, et contribue à l'amélioration des rendements culturaux.

Dans la pratique, la mise en œuvre et la réussite d'un système mixte sont beaucoup plus complexes dans la mesure où elles mettent en jeu d'autres éléments tels que le sol, le climat, la taille du cheptel, etc. En outre l'intégration élevage-agriculture n'est pas sans problème quand on connaît les problèmes fonciers que rencontrent certaines régions du Burkina Faso et le niveau de pauvreté des populations rurales Burkinabe. Ceci est corroboré par les conclusions des recherches de Slingerland (2000) sur les systèmes intégrés d'élevage et d'agriculture au Burkina Faso qui soulignent que le modèle d'intégration élevage-agriculture et spécialement le modèle mixte a un potentiel limité pour le développement des systèmes de production. Selon ce dernier, la population rurale burkinabé est dominée par un nombre élevé de paysans à faibles ressources, incapables d'adopter des technologies associées à un système mixte du fait de leur faible pouvoir d'achat.

Quelques exemples d'intégration élevage-agriculture dans des villages du Burkina Faso

De Ridder et *al*. (2002) ont mené des études dans un certain nombre de villages du Burkina Faso et de la sous région. Ces études ont permis de mettre en évidence certaines disparités dans l'intégration des produits de l'élevage à l'agriculture. Ces disparités ne semblent pas forcément liées à une appartenance à un étage bioclimatique donné.

Prenant le cas du village de Pentouangou (province du Gourma) l'étude de De Ridder et *al*. (2002) a montré que les systèmes agricoles étaient encore dans les premiers stades de développement, à savoir la transition entre les systèmes de jachère et d'exploitation permanente. De grandes proportions de terre ne sont pas encore cultivées (95 %), les propriétaires de bétail sont peu nombreux, l'application du fumier sur les champs n'est pas encore une pratique courante et les résidus de culture, dans la plupart des cas, sont brûlés.

Par contre, le village de Sambouali (Province de la Kompienga), est dans un stade avancé dans la voie vers l'exploitation permanente des terres. Les systèmes agricoles à Sambouali sont caractérisés par une forte proportion de terres cultivées (60 %, terres en courtes jachères comprises) avec une gestion intensifiée de la fertilité des sols. Les agriculteurs possèdent plus de bétail dont ils exploitent le fumier pour leurs champs de case. Les résidus de culture y sont beaucoup moins brûlés par rapport à Pentouangou. Cependant, on ne note pas d'utilisation d'engrais minéraux.

A Kirsi (province du Passoré), les systèmes sont encore plus avancés. Les superficies sont très importantes (près de 100 % des terres cultivables), le cheptel aussi y est important, ainsi que la quantité du fumier produit qui est fréquemment répandu sur les terres agricoles. A une échelle limitée, les agriculteurs commencent à utiliser des engrais minéraux.

Le village de Kiougou (Komyenga) est l'exemple en matière de développement de système agricole vers une utilisation permanente des terres agricoles : en plus des avancées rencontrées dans les précédents villages, on y trouve des cultures de rente comme le coton avec une utilisation beaucoup plus importante d'engrais minéraux.

Conclusion

La présente revue montre à la fois la simplicité et la complexité des interactions, des échanges élevage-agriculture. La simplicité de ces interactions vient du fait que ces deux systèmes, selon les sociétés, ont toujours existé l'un à côté de l'autre, l'un en partie dans l'autre, ou même en fusion presque totale. De là vient aussi la complexité de ces interactions ; il arrive qu'il existe une telle symbiose entre ces deux systèmes qu'en étudiant de près ces interactions, on se rend vite à l'évidence qu'on n'a pas entre les deux, des relations parfaites de cause à effet, des relations totales, ni même des relations de symétrie. A l'échelle microscopique, on découvre qu'entre agriculture et l'élevage il existe des éléments intermédiaires qui, en fonction de leur nature, de leurs spécificités, influent sur la relation élevage-agriculture. On serait en présence d'une fonction ''fertilité'', une variable indépendante ''fumure organique'' et un jeu de paramètres (nature du sol, climat, végétation, microfaune, etc.).

On l'aura compris, l'étude de la contribution des systèmes de production animale à la fertilité du sol fait intervenir des paramètres sol et végétation. Le paramètre sol désigne ici sa structure et sa texture. Le paramètre végétation est assez intéressant dans le sens où il est aussi large qu'est la végétation elle-même. Dans la végétation, si nous incluons les cultures, alors il en découle que la fertilité d'un sol, même avec un apport de fumure organique, reste fortement liée aux précédents culturaux par exemple, et à la présence ou non de résidus de culture.

Pour certains auteurs, la fertilisation d'un sol reposerait principalement sur la présence de la fumure organique et de l'accès du bétail aux résidus de culture. En effet, de nombreuses études faites dans le sahel montrent une amélioration significative de la structure des sols et des champs de culture dans les systèmes où les résidus de culture sont utilisés dans l'alimentation du bétail, et le fumier répandu sur le sol (Bationo & Mokwunye (1991); Somda (1994).

Afin d'évaluer avec plus de précisions la contribution des systèmes de production animale (SPA) à la fertilité des sols par la fumure organique, il conviendrait, d'initier une étude à l'échelle nationale sur les SPA (sous produits agricoles) ainsi que leurs potentialités en terme de production de fumier. Alors, suivant le système de production, on serait à mesure de déterminer à peu près les quantités réellement récupérables.

Nous ne devons pas ignorer ici l'urgence que représente la protection de nos sols assez fragiles. Les agriculteurs et tous les acteurs du développement rural sont conscients de la nécessité d'agir urgemment mais force est de reconnaître que dans la pratique il reste encore d'énormes retards à rattraper. A titre d'illustration, en 1997, selon Sawadogo (1997), seulement 15% des exploitants avaient adopté des techniques de luttes anti-érosives, 9% des exploitants utilisaient des engrais organiques et 8% pratiquaient l'agroforesterie.

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Chapter15

Economic Evaluation of Water and Nutrient Management Technologies in Ghana

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Abstract

Declining soil fertility and water stress are major constraints to agricultural production in Ghana. The former constraint is the result of a combination of factors including soil erosion, continuous cropping, bush burning and overgrazing, among others. A number of technologies have been developed to address these constraints without the needed economic evaluation to determine their feasibility before recommendation to farmers. In this review the indication is that, adoption studies, constraint analysis, short-term feasibility, as well as the long-term sustainability of some of the technologies have been carried out. While the review is meant to give readers an overview of the economic feasibility of such technologies to enable informed decisions on the type of technologies to be recommended to farmers, it also provides a basis for future economic evaluations of water and nutrient management technologies by filling in information gaps. Most of the data used for these evaluations came from on-station research. Consequently, performance of the technologies on farmers' fields would be necessary for relevant recommendations to be made. Performing economic evaluation of technologies using on-farm research data is therefore recommended. The technologies in this review that were economically evaluated are mainly manure and cover crops technologies, which have long-term effects. Thus, instead of using partial productivity measure in the evaluation of these technologies as has been the case, Total Factor Productivities (TFP) should be used. In view of the lack of data for carrying out economic evaluation of technologies, it is also recommended that future technology development efforts take into account the building-up of socio-economic database.

Key Word: *Economic evaluation, partial budgeting, soil fertility technologies, soil water, Ghana.*

Résumé

Le stress hydrique et la baisse de la fertilite des sols sont les contraintes majeures à la production agricole au Ghana. Avant, la contrainte etait le resultat d'une combinaison de facteurs tells que l'erosion, la culture continue, le feu de brousse et le surpaturage, etc. Un certain nombre de techniques ont ete developpees pour lutter contre ces contraintes mais sans evaluation economique determinant leur faisabilite avant d'etre recommandees aux paysans. Dans cette revue de literature sur l'evaluation economique des techniques de gestion des nutiments et de l'eau au Ghana, il resort que les etudes d'adoption, d'analyses de contraintes, de faisabilite à court terme, de durabilite du long-teme ont ete menees. En meme temps que la revue fait aux lecteurs un apercu sur la faisabilite economique des techniques pour permettre aux decideurs de faire le choix de celles à recommender aux paysans, elle procure une base d'evaluations economiques des techniques de gestion de l'eau et des nutriments pour le future en comblant les gaps d'information. La pluspart des donnees utilisees proviennent des recherches en station. Consequenment, la performance des techniques sur les tests paysans serait necessaire pour faire des recommendations appropriees. Une evaluation economique performante sur les techniques utilisant les donnees des tests paysans est donc recommandee. Les techniques qui sont evaluees economiquement dans cette revue sont principallement celles du fumier et des plantes de couverture qui ont des effets à long-terme. Ainsi, au lieu de faire une mesure partielle de la productivite dans l'evaluation des techniques comme ce fut le cas, la productivite de tous les facteurs (PTF)doit etre utilisee. Vu le manqué de donnees pour mener l'evaluation economique des techniques, il est aussi recommande le developpement des techniques futurs prenne en compte la mise en place d'une base de donnees socio-economique.

Mots cles: *Evaluation economique, budgetization partielle, techniques de fertilite des sols, Ghana, l'eau du sol.*

Introduction

Agriculture is the mainstay of the economy of Ghana, accounting for 50% of Gross Domestic Product (GDP). Agricultural production in Ghana takes place in the rural areas where majority of households depend on crop production with some amount of animal production as their means of livelihood.

Historically, agricultural production in Ghana took the form of slash and burn shifting cultivation system. This system of cultivation had the advantage of ensuring soil fertility restoration through long fallow periods of up to fifteen years. It has been stated that a minimum of eight years of fallow is required to restore soil fertility in the tropics including Ghana (Tshibaka, 1989). However, over time, population pressure has resulted in continuous cropping of land with the associated decline in soil fertility and reduced crop yields. In northern Ghana especially, land is intensively cultivated. A direct consequence of intensive land cultivation without proper soil management is land degradation. This situation, require the development of appropriate technologies to address the declining soil fertility and the consequent low crop yields.

Another constraint that usually intensifies the effect of declining soil fertility in Ghana is the erratic rainfall pattern. In the northern part of Ghana, rainfall is often inadequate in amount as well as distribution, receiving the least annual precipitation. With the situation often worsened by dry spells, which are frequent during the cropping season, the use of water management technologies for crop production is becoming more and more inevitable.

A number of technologies have been developed through research to address this constraint of declining soil fertility and moisture stress. Some of these technologies include the use of appropriate crop rotation systems, use of chemical and organic fertilizers (mainly animal manure and compost). Others are technologies on water harvesting and retention in soils. In the main however, the development of these technologies have largely been based on technical feasibility, which by itself, is not a sufficient condition for the recommendation of the technologies to farmers. There is also a need for economic feasibility in addition to technical feasibility to achieve a sufficient condition for making recommendations to farmers. It was against this background that attempts were made to carry out economic evaluation of some of the technologies developed to address the declining soil fertility problem through a cost-effective water and nutrient management.

This paper is a review of work done in terms of economic evaluation of water and nutrient management technologies in Ghana. The review is meant to give the reader an overview of the economic feasibility of such technologies for informed decisions to be made on what technologies to recommend to farmers for a higher likelihood of adoption. It also provides a basis for future economic evaluations of water and nutrient management technologies by providing information gaps. The review process covered eight evaluations; summarizing each evaluation by focusing on the title, objectives, methodology, the main conclusions drawn and the gaps identified. It then discusses the evaluation in terms of its contribution to knowledge on water and nutrient management in Ghana. Finally, a synthesis of the evaluations is made and recommendations are suggested for the future direction of economic evaluation of water and nutrient management technologies as well as the evaluation of similar technologies.

Review of past economic evaluations of soil and water management technologies in Ghana

The review covered the following studies.

1. Analysis of some socio-economic factors that affect the adoption of agro-forestry technologies in the Yensi valley in Akwapim, Ghana;
2. The economics of alternative methods of soil fertility maintenance in the Guinea

Savanna zone of Ghana;

3. Socio-economic constraints to the use of animal manure in Northern Ghana;
4. Sustainability of maize-based cropping systems in Northern Ghana;
5. Economic analysis of soil fertility management practices in the Upper East Region of Ghana;
6. The economics of seedbed type and fertilizer rate on water use and grain yield of maize;
7. Economic Analysis of the Comparative response of Cowpea and Sorghum to Phosphorus fertilizer
8. Effect of preceding crop and N-fertilizer rate on Sorghum grain yield

Analysis of some socioeconomic factors that affect the adoption of agro-forestry technologies in the Yensi valley in Akwapim, Ghana

This study sought to achieve two major objectives:

i. to identify agro-forestry technologies that are capable of meeting the needs, objectives and goals of farmers in the Akwapim North district of the Eastern region of Ghana
ii. to analyze the socio-economic factors that affect the adoption of agro-forestry in the study area

Six agro-forestry technologies were specified in the study among others. A sample size of 56 households was used to estimate a probit model for the adoption of agro-forestry technologies using the Probit Maximum Likelihood approach (Sarfo-Mensah and S.J. Quarshie, 1993). This approach has been used by Akinola (1987) and Hailu (1990).

The results of this study indicated that two factors, land tenure status and annual average income, significantly affect the adoption of agro-forestry technologies in the study area. These factors were significant at the 10% and 5% levels of significance respectively. The study concluded that alley farming is the most preferred agro-forestry technology that has the potential of meeting the objectives and goals of farmers in the study area. The perception of farmers is that land tenure and credit issues are the most critical factors that affect adoption. Finally the study emphasized that the successful promotion of agro-forestry as a solution to the land use problems in the study area would depend on a flexible land tenure system and access to credit.

Although the study made a good attempt at establishing the factors affecting the adoption/non adoption of agro-forestry technologies, it has a number of flaws. These include:

i. A small sample size which was not adequate for the model approach used. For such a model a minimum sample size of 120 would be appropriate.
ii. Some of the variables specified in the model may have autocorrelation problems (household size and labor availability, access to off-farm employment and annual

average income) or even multicollinearity if are cross-sectional data are used.

iii. The authors tried to explain the effect of non-significant factors in the model. This is not a normal practice in adoption studies except in cases of "a priori" with expectations of high significance.

The economics of alternative methods of soil fertility maintenance in the Guinea Savanna zone of Ghana

Concern for low soil productivity that results from intensive cultivation motivated a number of institutions including the Savanna Agricultural Research Institute to embark upon methods of improving soil productivity. Langyintuo et al (1995) conducted an economic evaluation of the use of organic and inorganic fertilizers and cover crops as a means of maintaining soil fertility in Northern Ghana. They also reviewed the superiority of crop rotation over mono-cropping and intercropping in the existing farming systems of the area. The evaluation made use of secondary data collected both on-station and on-farm by the Savanna Agricultural Research Institute. The test crops in the analysis were rice and maize, whose choice was influenced by data availability. Partial budgeting techniques were employed in the analysis for organic fertilizers and cover crops while price ratios were used for inorganic fertilizers due to lack of adequate data to conduct partial budgeting.

Price ratio of maize to inorganic fertilizers over the period 1979 to 1986 suggested that fertilizer prices continued to rise relative to maize prices (Table 1). As a result, the use of inorganic fertilizers continued to decline to the effect that in 1993 90% of all fields in northern Ghana did not receive any inorganic fertilizers. It was only in the Northern Region that 16% of fields received inorganic fertilizers as farmers were not able to buy fertilizers for application to their farms.

Table 1: Ratio of maize to inorganic fertilizer prices

Year	Maize price (¢/ 100kg)	Price ratio of maize / compound fertilizer	Price ratio of maize / sulphate of ammonia
1979	80	1:8	1:10
1980	100	1:6	1:8.3
1981	165	1:5.5	1:6.6
1982	500	1:9.4	1:13.2
1983	1800	1:34	1:47.4
1984	1000	1:2.5	1:3.4
1985	2000	1:4.5	1:6.8
1986	2600	1:3.5	1:5.3

Source: Hailu (1990)

The analysis of organic fertilizer use denoted that the concentration of Nitrogen in cow dung in Northern Ghana is twice that of sheep and goats, but the authors were quick to add that the production of sheep and goats' droppings should not be neglected. The amount of Nitrogen in cow dung however has also been found to depend on the method of storage of the dung. Partial budget analysis indicates that

1 ton of cow dung per hectare of maize is more economical than 4 tons of cow dung per hectare or 50-30-30 kg NPK/ha. Given that fallow periods are getting shorter, it is envisaged that the incorporation of a leguminous non-food crop in fallows could be an advantage. Other studies indicate that the inclusion of *Callopogonium mucunoides* in a two-year fallow supplies 75% of the recommended level of nitrogen of 60 kg /ha for rice production. The analysis suggests that rice be grown on land under *Callopogonium* fallow with some amount of inorganic fertilizer input.

A review of intercropping, mono-cropping and crop rotation, (Peter and Runge-Metzger, 1994) indicates that traditional cropping enterprises combined with crop rotation are superior to intercropping or mono-cropping using gross margin analysis.

The above analyses provide some insights into the management of soil fertility for crop production in the face of declining fertility as a result of causes already discussed. The results can only be used as a guide and not a blue print as part of the database used came from estimates. Besides, the use of organic fertilizers such as cow dung provide medium to long term effects and benefits are expected over a period of time, making discounted cash measures more appropriate than the method of analysis used.

Socio-economic constraints to the use of animal manure in northern Ghana

Between the 1960s and 1970s, inorganic fertilizers received a subsidy of up to 80%. The subsidy was gradually reduced beginning in the early eighties and was finally withdrawn by 1990. This made inorganic fertilizers increasingly inaccessible to farmers as the price rose with the passage of time. The use of manure for crop production became an important alternative to inorganic fertilizers. However, little was known about the constraints to the use of organic manure for soil fertility improvement. Langyintuo and Karbo (1998) studied the constraints to the use of animal manure. They used data that was collected from 420 farmers in three districts of the Northern Region in 1993/94.

The results of this study indicate that farmers are well aware of the benefits of using animal manure but a number of constraints militate against its use. First, the available manure is inadequate in terms of quantity produced. Fernandez-Rivera et al (1993) enumerated some factors affecting the amount of manure available for crop production. Other constraints to the use of animal manure include the introduction of foreign weeds, high labor demand and joint ownership of cattle. Some farmers simply stated that their farms were fertile and so they did not need to use animal manure.

Langyintuo and Karbo (1998) conclude from their findings that the adoption of the use of animal manure would be facilitated by the integration of crop and livestock enterprises for more and better manure with high nitrogen content, adding that appropriate storage methods for manure were important in minimizing Nitrogen loses and this should be emphasized by agricultural extension workers.

Sustainability of maize-based cropping systems in northern Ghana

Maize is an important staple food crop in Ghana and as such, an important study of some of the traditional maize-based cropping systems was carried out at Nyankpala over the period 1984 – 1987 to assess the interrelationships and interactions between maize and cowpea with regard to the utilization of water and nutrient supply (Härdter, 1989). This study provided a database for an assessment of the sustenance of maize-based cropping systems in northern Ghana by Abatania (1998). The study was motivated by the lack of quantitative assessment of the operation of these cropping systems in Ghana. The approach of Total Factor Productivity (TFP) was used to assess the long run sustainability (continuity) of the cropping systems studied. This approach has been used by Traxler et al (1995) as well as Ehui and Spencer (1990) to assess adoption sustainability by farmers. A production system that is sustainable in the long run must be profitable in the short run. Thus short run profitability was assessed as a necessary condition for assessing the long run sustainability of the systems.

Results of the above assessment indicate that maize-cowpea relay intercropping and sole maize continuously cropped are sustainable when natural resource flows are accounted for. On the other hand, maize-cowpea rotation, maize-cowpea intercropping as well as maize-sorghum-groundnut mixed intercropping are not sustainable. On this basis, the assessment recommends that cereal-legume mixtures should be rotated with sole legumes where these are grown as this may move the systems towards sustainability. Labor had the highest cost share in all the systems assessed. It recommended that labor-saving devices be adopted as this would greatly enhance the sustainability of cropping systems. This assessment is the first of its kind in the literature on Ghana. It provides a good reference for assessing the sustainability of other production systems.

Economic analysis of soil fertility management practices in the Upper East region of Ghana

The Upper East Region is the smallest region in Ghana in terms of land area. The region is characterized by high population density and very poor soils. The Upper East Region Land Conservation and Smallholder rehabilitation Project (1992) noted that provided adequate measures are taken to improve the soil structure and fertility, these soils would be suitable for pasture, tree crops and sustainable annual crop production. Terbobri (1999) carried out an economic evaluation of soil fertility management (SFM) practices in the region as efforts were being made to provide such adequate measures suggested by the land conservation project mentioned above. The evaluation involved the estimation of partial budgets, value-cost ratios, marginal rates of return and constraint analysis of eight soil fertility management techniques as follows:

i. Farmers' practice of continuous cropping without soil nutrient amendments
ii. 60-40-40 kg NPK as inorganic fertilizer per hectare (kg ha^{-1})
iii. 4 tons ha^{-1} cowdung
iv. 8 tons ha^{-1} cowdung
v. 2 tons cowdung + 30-20-20 kg NPK (kg ha^{-1})
vi. 4 tons cowdung + 30-20-20 kg NPK (kg ha^{-1})
vii. 4 tons cowdung + 60-40-40 kg NPK (kg ha^{-1})
viii. Application of 8 tons cowdung + 60-40-40 kg NPK (kg ha^{-1})

The results of this analysis indicate the superiority of manure application over the use of inorganic fertilizers. The highest value-cost ratio was obtained with 4 tons of manure per hectare, followed by 8 tons of manure per hectare. A marginal rate of return of 78.2% was obtained by moving from the application of 4 tons of manure to 8 tons of manure per hectare. Constraint analysis pointed to the fact that labor and capital are the major constraint to the use of SFM techniques. Further analysis suggests manure use would be the best option and 8 tons of cow dung per hectare is the optimum level to apply.

The economics of seedbed type and fertilizer rate on water use and grain yield of maize

Erratic rainfall pattern often leads to moisture stress for arable crops in the savanna. Soil moisture influences the efficiency with which nutrients from chemical fertilizers are used. The type of seedbed used can have an effect on soil moisture. It is in the light of the above relationships that Buah and Abatania (2000) set up an experiment to investigate the combined effect of seedbed type and inorganic fertilizer use on rain water management and crop production using maize as test crop.

The experiment involved three seedbed types: (i) Flat, (ii) Ridges and (iii) Tied Ridges. Four fertilizer rates were superimposed on each seedbed type as follows:

(i) F1: No fertilizer input
(ii) F2: 1 bag 15-15-15 NPK plus 1 bag Sulphate of ammonia (SAN)
(iii) F3: 2 bags 15-15-15 NPK plus 1 bag SAN
(iv) F4: 2 bags each of 15-15-15 NPK and SAS

(1 bag fertilizer = 50 kilograms)

Partial budget analysis was carried out on the data obtained. Holding seedbed type constant gross returns, variable costs and net returns all showed an increase with increase in inorganic fertilizer input. The highest net return was obtained with tied ridges combined with 2 bags of 15-15-15 NPK plus 2 bags of Sulphate of ammonia. Generally, tied ridges had the highest net returns for each level of inorganic fertilizer input. This conforms to *a priori* expectation. Tied ridges are expected to be more effective in conserving soil moisture for the efficient use of inorganic fertilizer.

Ridges performed poorly compared with Flat at lower fertilizer levels (F1 and F2) but were superior at higher levels of fertilizer input (F3 and F4) (Table 2). This again was expected to be the case. At lower levels of inorganic fertilizer, moisture may not be a limiting factor. The higher net returns obtained with Flats at the lower levels of fertilizer may be due to soil differences other than moisture and fertilizer. As fertilizer level increases, moisture becomes a limiting factor. Ridges are expected to conserve moisture better than Flat. Hence the trends observed in net returns.

Table 2: Partial budgets of Maize under different seedbed types and fertilizer rate

Treatment	Gross return	Variable cost	Net return
TRF1	1,155,440	86,800	1,068,640
TRF2	2,989,360	556,760	2,432,600
TRF3	3,784,000	817,780	2,966,220
TRF4	4,675,440	995,100	3,680,340
RF1	715,440	50,220	665,220
RF2	2,610960	520,180	2,090,780
RF3	3,813,040	781,200	3,031,840
RF4	4,599,760	958,520	3,641,240
FLF1	888,800	55,180	833,620
FLF2	2,901,360	525,140	2,376,220
FLF3	3,549,040	786,160	2,762,880
FLF4	4,314,640	963,480	3,351,160

TRF1-4: Tied Ridge Fertilizer rates 1 - 4; RF1-4: Ridge Fertilizer rates 1 - 4; FLF1-4: Flat Bed fertilizer rates 1 - 4

Source: Buah and Abatania (2000)

Economic Analysis of the Comparative response of Cowpea and Sorghum to Phosphorus fertilizer

Cowpea and Sorghum are important food crops among households of the Upper West region of Ghana. Phosphorus is a major nutrient in the production of both crops. Information is however not available on the amount and frequency of application of P fertilizer. An experiment was therefore set up to determine if infrequently applying fertilizer P to the soil would enhance soil P availability enough to maintain both Cowpea and Sorghum yields, or if annual application would be required. This experiment was implemented from 2000 to 2004. This review covers the period 2000 – 2002, Buah and Abatania (2003).

Partial budgets calculated annually for each of the crops under the various treatments indicate that for Cowpea, net returns for direct and annual P application were the same for 2000 and 2001. The net returns as a result of direct or cumulative application of P fertilizer in Cowpea increased between 0 and 30 kg Pha^{-1} and began to decrease with increases in P application. In other words, Cowpea yields increased with fertilizer application of between 0 and 30 kg P ha^{-1}. Beyond this level, yields decreased with corresponding increases in P application. For residual P application in Cowpea, net returns increased with increases in P applied up to 90 kg Pha^{-1}. The previous season's results showed a decrease in net return after 60 kg Pha^{-1}. The highest net return was obtained with residual P applied at 90 kg Pha^{-1}. Thus for three cropping seasons the results indicate that when cowpea is grown in rotation with sorghum, it is better to apply P fertilizer to the sorghum crop and allow cowpea to benefit from the residual P effect. Similarly, the analysis for sorghum suggest that when cowpea is grown in rotation with sorghum, P fertilizer should be applied directly to cowpea so that sorghum would benefit from the residual effect. Both crops showed highest net returns for residual P application.

What this evaluation has failed to do is to establish the crop to which Phosphorus fertilizer should be applied in order for the other crops to benefit from the residual effect. To do this, a cash flow table would have to be established for the period of the experiment showing a discounted present value of the net benefits.

Effect of previous crop on the response of sorghum grain yield to Nitrogen fertilizer

Sorghum is an important food crop with an industrial potential. The crop is grown mainly in Northern Ghana under varied cropping systems and patterns. It is believed that sorghum benefits from soil improvement when it follows leguminous crops in the rotation. Farmers are also known to plant sorghum after legumes. Additionally, the crop requires Nitrogen fertilizer input. However, the optimal rates of fertilizer to apply is not known. The lack of information on the best preceding crop to sorghum and Nitrogen level to apply led to the implantation of an on-station experiment in the Upper West region of Ghana, Buah and Abatania (2002). The main objective of the experiment was to find out the best preceding crop and Nitrogen fertilizer rate for sorghum production in the Upper West region of Ghana. The main plots were four preceding crops (cowpea, groundnut, soybean and sorghum). Four rates of Nitrogen (0, 40, 80, 120 kg N ha^{-1}) constituted the subplots.

Partial budget analysis, at the end of the second season of the experiment, indicated that when no Nitrogen fertilizer is applied soybean is the best preceding crop to sorghum. As Nitrogen fertilizer is applied, cowpea and soybean as preceding crops show increases in net returns up to 80 kg N ha^{-1}, thereafter declining with further Nitrogen application. Corresponding figures were higher for cowpea than for soybean. Groundnut and sorghum as preceding crops exhibited consistent increases in net return with increase in Nitrogen fertilizer application. Corresponding figures were higher for groundnut than for sorghum as a preceding crop. Indeed all the leguminous preceding crops showed corresponding higher net return values than sorghum. This reaffirmed the assertion that sorghum benefits from legumes as preceding crops in the rotation. The highest net return was obtained using groundnut as a preceding crop with 120 kg N ha^{-1}.

With the experiment still on-going, no definite recommendations could be made at this stage. However, groundnut promises to be the best preceding crop for sorghum if net returns follow the same trends in subsequent seasons.

Synthesis: Economic evaluation of water and nutrient management technologies in Ghana

Declining soil fertility and water stress are major problems to crop production in Ghana. Much effort has been made at developing technologies for nutrient and water management to address these problems. The focus of technology development has been on technical aspects. The importance of economic feasibility in recommending technologies to farmers led to the economic evaluation of some of the technologies developed. Economic evaluations have been constrained by availability of relevant data. The economic evaluations carried out so far have dealt with partial productivity measures such as crop yield as a basis for analysis with short-term feasibility measures. However, some of the technologies evaluated have long-term implications (for example, the use of manures and cover crops). Economic evaluation of water and nutrient management technologies should include total productivity as well as long-term sustainability measures. It is in the light of this that one of the evaluations - the sustainability of maize-based cropping systems in Northern Ghana- stand out for emulation.

As the part of the country with the most serious declining soil fertility constraints, economic evaluations carried out so far are focused on northern Ghana (Table 3). The rest of the country receives relatively better, though declining rainfall and has soils that are more supportive to crops.

Conclusions and recommendations

This review has brought to light the kinds of economic evaluation of water and nutrient management that have been carried out in Ghana. The evaluations have covered the factors that affect the adoption of nutrient management technologies, made comparative analysis of technologies developed and assessed the long-term sustainability of some technologies. The constraints to the use of nutrient management technologies have also been dealt with in these economic evaluations.

By and large, economic evaluation of water and nutrient management technologies in Ghana are based on on-station experimental data. Thus, the results from these evaluations are far from forming a basis for making reliable recommendations to farmers. These technologies have to be tested on-farm and the necessary comparative economic or socio-economic evaluation carried out with data generated on-farm and by farmers.

In view of the importance of these evaluations, water and nutrient management technologies in Ghana or any technology development process must include a social and economic evaluation of the technology. Given that the lack of data has been largely responsible for the unavailability of economic evaluation for some technologies,

Table 3: Synthesis of technologies

Title	objective	Methodology	Main conclusions	Gaps identified
Analysis of some socioeconomic factors that affect the adoption of agro-forestry technologies in the Yensi valley in Akwapim, Ghana	- To identify agro-forestry technologies capable of meeting the needs, objectives and goals of farmers - To analyze the socio-economic factors affecting the adoption of agro-forestry in the study area	Probit Maximum Likelihood approach	land tenure status and annual average income, significantly affect the adoption of agro-forestry technologies in the study area.	- Sample size of 56 too small for model. - Autocorrelation or even multicollinearity if cross-sectional data are used. - Explaining the effect of non-significant factors in the model normal practice in adoption studies except in cases of "a priori" with expectations of high significance.
The economics of alternative methods of soil fertility maintenance in the Guinea Savanna zone of Ghana	- To determine the economics of crop rotation, mono cropping and mixed cropping	- Partial budgeting techniques for organic fertilizers and cover crops - Price ratios were used for inorganic fertilizers - Gross margin analysis.	- Fertilizer prices continued to rise relative to maize prices - Traditional cropping enterprises combined with crop rotation are superior to intercropping or mono-cropping.	- Discounted cash measures more appropriate than the method of analysis used.
Socio-economic constraints to the use of animal manure in northern Ghana	- To identify the constraints to the use of manure for crop production	Statistical inferences with data from 420 farmers	- The available manure is inadequate in terms of quantity produced - The introduction of foreign weeds, high labor demand and joint ownership of cattle. - The adoption of manure would be facilitated by the integration of crop and livestock enterprises - Appropriate storage methods for manure were important in minimizing Nitrogen loses - And this should be emphasized by agricultural extension workers.	

Sustainability of maize-based cropping systems in northern Ghana	to assess the interrelationships and interactions between maize and cowpea with regard to the utilization of water and nutrient supply	Total Factor Productivity (TFP) was used to assess the long run sustainability (continuity) of the cropping systems studied	- Maize-cowpea relay intercropping and sole maize continuously cropped are sustainable when natural resource flows are accounted for. - It recommended that labor-saving devices be adopted as this would greatly enhance the sustainability of cropping systems.	Nil
Economic analysis of soil fertility management practices in the Upper East region of Ghana	To determine the optimum levels of alternative combinations of manure and fertilizers.	- partial budgets, value-cost ratios, marginal rates of return and constraint analysis	- Analysis indicate the superiority of manure application over the use of inorganic fertilizers. - Constraint analysis pointed to the fact that labor and capital are the major constraint to the use of SFM techniques. - Manure use would be the best option and 8 tons of cow dung per hectare is the optimum level	Nil
The economics of seedbed type and fertilizer rate on water use and grain yield of maize	to investigate the combined effect of seedbed type and inorganic fertilizer use on rain water management and crop production using maize as test crop	The experiment involved three seedbed types: (i) Flat, (ii) Ridges and (iii) Tied Ridges. Four fertilizer rates were superimposed on each seedbed type as follows: - F1: No fertilizer input - F2: 1 bag 15-15-15 NPK plus 1 bag Sulphate of ammonia (SAN) - F3: 2 bags 15-15-15 NPK plus 1 bag SAN - F4: 2 bags each of 15-15-15 NPK and SAS - Partial budget analysis on data obtained	The highest net return was obtained with tied ridges combined with 2 bags of 15-15-15 NPK plus 2 bags of Sulphate of ammonia. Generally, tied ridges had the highest net returns for each level of inorganic fertilizer input. This conforms to *a priori* expectation.	Nil

Economic Analysis of the Comparative response of Cowpea and Sorghum to Phosphorus fertilizer	to determine if infrequently applying fertilizer P to the soil would enhance soil P availability enough to maintain both Cowpea and Sorghum yields, or if annual application would be required.	Partial budgets calculated annually for each of the crops under the various treatments	- results indicate that when cowpea is grown in rotation with sorghum, it is better to apply P fertilizer to the sorghum crop and allow cowpea to benefit from the residual P effect. - Similarly, the analysis for sorghum suggest that when cowpea is grown in rotation with sorghum, P fertilizer should be applied directly to cowpea so that sorghum would benefit from the residual effect. Both crops showed highest net returns for residual P application.	What this evaluation has failed to do is to establish the crop to which Phosphorus fertilizer should be applied in order for the other crops to benefit from the residual effect
Effect of previous crop on the response of sorghum grain yield to Nitrogen fertilizer	to find out the best preceding crop and Nitrogen fertilizer rate for sorghum production in the Upper West region of Ghana.	Partial budget analysis	With the experiment still on-going, no definite recommendations could be made at this stage. However, groundnut promises to be the best preceding crop for sorghum if net returns follow the same trends in subsequent seasons.	Experiment still on-going

every effort must be made to generate the requisite socio-economic database during the development of technologies. In this regard, the present evaluations that have been reviewed would provide some guidelines on what data to collect for economic evaluation of the technologies. Indeed, much more needs to be done in terms of economic evaluation of water and nutrient management technologies in Ghana in the future.

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Chapter 16

Cropping Systems: With particular emphasis on dry season vegetable production in Ghana.

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Abstract

In Ghana the main vegetables grown include tomato (*Lycopersicum esculentum*), onion (*Allium cepa L.*), shallots (*Allium cepa var ascalonicum Don*), pepper, okra, garden eggs, Kontomire (cocoyam leaves), Carrots, (Cowpea leaves, Alefi leaves (*Amaranthus incurvatus*), Lettuce, Cabbage, Sweet potato leaves (*Ipomea batatas*) and Eyoyio leaves (*Corchurus tridens*). However there are others, which are less known or under-utilised. The green leaf vegetable "Bokoboko" (*Talinum triangulare*) and the unripe pawpaw (*Carica papaya L.*) fruit are examples. In the northern part of the country vegetables are usually cultivated during the dry season along dam sites, dug-outs and wells and also during the rainy season, while in the southern part they are often grown in the Home garden within the compound of individual houses and also along water-ways in the cities. Due to the fast growing population, the high demand for these vegetables and a deficit in production, there is a need to increase the production of both local and exotic vegetables in urban areas to meet the nutritional requirements of the people. Unlike other crops such as cereal, legumes and root and tuber crops there has been very little research on both local and exotic vegetable crops in the Ghana. This chapter reviews the little research that has been conducted in Ghana on the vegetable crop and discusses potential future research areas.

Key words: *Vegetables, dry season, tomato, onion, lettuce, sweet potato, Ghana*

Résumé

Au Ghana les légumes principales qui sont cultivées incluent la tomate (*Lycopersicum esculentum*), l' oignon (*Allium cepa* L.), shallots (*Allium cepa* var *ascalonicum* Don), le piment, le gombo, l' aubergine, le kontomire (feuilles de cocoyam), la carrotte, les feuilles du niébé, les feuilles d' Alefi (*Amaranthus incurvatus*), la salade, la choux, les feuilles de la patate douce (*Ipomea batatas*), et les feuilles d' Eyoyion (*Corchurus tridens*). Cependant il y' a en d' autres qui ne sont pas bien connues ou pas suffisamment utilisées. Les feuilles des légumes vertes « Bokoboko » (*Talinum triangulare*) et les fruits de la papaya non-mure (*Carica papaya* L.) sont quelques exemples. Dans la partie nord du pays les légumes sont généralement cultivées pendant la saison sèche tout au long des barrages, les reservoirs et les puits et aussi pendant l' hivernage alors que dans la partie sud du pays ces légumes sont cultivées dans les jardins des cases au sein de la cour des maisons individuelles et aussi tout au long des canaux d' eau dans les villes. A cause de la forte croissance démographique, la demande élévée pour ces légumes et un déficite en production, il est important d' augmenter la production des légumes tant locales qu' éxotiques dans les centres urbains afin de repondre aux besoins nutritionnels des populations. Contrairement aux autres cultures telles que les céréales, les légumineuses et les tubercules, très peu de recherche a été faite sur les légumes locales et exotiques au Ghana. Ce chapitre fait la revue de la recherche limitée qui a été faite sur les légumes au Ghana et discute des axes potentiels de recherche future.

Mots cléfs: *Légumes, saison sèche, tomate, oignon, salade, patate douce, Ghana*

Introduction

The word vegetable has been defined as "an edible plant part that is used as human food and is usually eaten cooked or raw as the main part of a meal rather than a dessert". In Ghana the main vegetables grown include tomato (*Lycopersicum esculentum*), onion (*Allium cepa* L.), shallots (*Allium cepa* var *ascalonicum* Don), pepper (*Capsicum* spp), okra (*Hibiscus esculentus*), garden eggs (*Solanum melongena*), Kontomire (cocoyam leaves), Carrots (*Daucus carota*), Cowpea (*Vigna unguiculata*) leaves, Alefi leaves (*Amaranthus incurvatus*), Lettuce (*Lactuca sativa*), Cabbage (*Brasica oleracea* var. *botrytis*), Sweet potato leaves (*Ipomea batatas*) and Eyoyio leaves (*Corchurus tridens*). However there are others, which are less known or under-utilised. The green leaf vegetable "Bokoboko" (*Talinum triangulare*) and the unripe pawpaw (*Carica papaya* L.) fruit are examples. In Ghana there are two systems of vegetable cultivation. In northern Ghana vegetables are usually cultivated in the dry season along dam sites, dug-outs and wells and also during the rainy season, whiles in southern Ghana vegetables are usually grown in the Home garden within the compound of individual houses and also long water-ways in the cities. In recent times the need to commercially produce both local and exotic vegetables in urban areas as well as in the hinterland to the nutritional needs of the growing population. Regrettably what is currently produced does not come anywhere near what the country requires annually. To cope with the huge production deficit the country has to spend huge sums of hard-earned foreign currency to import vegetables from both surrounding countries and elsewhere. Unlike other crops such as cereal, legumes and root and tuber crops there has been very little research on both local and exotic vegetable crops in the Ghana. This Chapter will review and discuss the research that has been conducted in the country on the vegetable crop and to identify possible areas for future research efforts with a view to improving upon vegetable production in the country. The review will concentrate on the areas of agronomy, breeding, protection, storage and quality and socio-economic studies.

Agronomic research

Susceptibility of shallots to the timing and severity of leaf damage was investigated under field conditions. The objective of the study was to determine the critical period and extent to which defoliation will influence shallot growth, bulb yield and quality.

Shallots maturity measured as percentage topfall was significantly ($p<0.05$) early in the intact and 50% defoliated plants, but delayed in the severely defoliated plants. Bartolo *et al*. (1994) have also made a similar report in an earlier study with onion. Bulb size differed among treatments with the control intact shallot plants recording bigger bulbs compared to the other treatments. The Control gave significantly ($p<0.05$) bigger bulbs compared to defoliated shallots at 6 weeks after planting (WAP) at 75% and 100% and also at 8 WAP at all levels of defoliation (Table 1). Both timing and severity of defoliation significantly reduced shallot bulb weight except at 50% defoliation. 100% defoliation produced the lightest bulbs at all times. Fresh bulb scales, which are derivatives of leaves, are an important indication of *Allium* quality decreased with increasing severity of defoliation and growth stage. Bulb shape index was only significantly influenced at 100% defoliation at the 6 and 8 WAP compared to the Control. Sucrose content was highest when shallots were defoliated at 4 WAP at a severity of 50% and least at 6WAP at 100%. The results of the study are consistent with those reported by other workers Bartolo *et al*. (1994) and Muro *et al*. (1991).

Table 1: Effect of defoliation on maturity, bulb size, bulb weight, bulb scale, bulb shape index and sucrose content of shallots subjected to different degrees of leaf damage at different growth stages

Defoliation	Topfall (%)	Bulb size (g)	Bulb weight (g)	Fresh bulb scale no.	Bulb shape index	Sucrose content (%)
Control 0%	74.3a[1]	2.5a[1]	16.3a	9.5a	1.2c	9.9a
4WAP						
50%	75.0a	2.3abc	14.7ab	8.6a	1.3bc	10.0a
75%	28.0b	2.4ab	11.1cd	8.7a	1.3bc	6.9ab
100%	5.7	2.4ab	9.0dc	9.0a	1.4bc	9.6ab
6WAP						
50%	77.7a	2.3abc	13.9abc	8.2a	1.3bc	9.6ab
75%	61.0a	2.0c	12.0bcd	8.0ab	1.4bc	7.4ab
100%	26.7b	1.5d	6.8c	5.9bc	1.7a	6.1b
8WAP						
50%	70.0a	2.1bc	13.7abc	7.9ab	1.4bc	8.3ab
75%	22.0bc	2.0bc	9.9d	8.1ab	1.4bc	9.9ab
100%	11.7bc	1.9cd	6.1c	5.5c	1.5ab	6.6ab

[1]*Mean separation within columns by Duncan's multiple range test at P<0.05*

Source: Abbey et al., 1998

Density affects plant development and yield of bulb onion (Allium cepa L.) in Northern Ghana.

The yields of onion in Ghana are far lower (10.3 to 14.0 t ha^{-1}) than those obtained in neighbouring countries, and one of the reasons for this lower onion yields is lack of optimal agronomic practices. In an effort to address this, a number of agronomic field trials were conducted the results of some of which are discussed. The study (Kanton *et al*., 2002) was conducted at two sites, however location effect was not significant ($p<0.05$). Onion growth, development, yield and its components were significantly ($p<0.05$) affected by plant spacing and population density. Plant height decreased as population density increased. Plant height at the lowest density 37 plants per metre squared was 20% greater than those above 76 plants m^{-2} (Fig. 1a). Percent marketable bulbs increased as population density increased (Fig. 1b), but percent of cull bulbs decreased as density increased. Mean bulb weight decreased as density increased, with the lowest plant density producing bulbs that were 128% greater than those from at the highest density (Fig. 1c). Bulbing index which is the inner sheath diameter to that of maximum bulb diameter, increased as density increased. Onion bulb yield similarly increased at higher density with the highest bulb yield 43% greater than the lowest (Fig. 1d). The results of the study indicated that the bulb yield of the local onion could be increased 3 to 5 times of the current yields, which range from 7 to 14 t ha^{-1}. The higher bulb yields reported are consistent with those reported in the literature Farghali and Zeid (1995), Singh (1995), Stofella (1996) and Galmarini *et al*., (1995). Frappell (1973) in a study on onion spacing concluded that it is desirable that markets are developed for all size grades and that high densities from a practical viewpoint is important since it permits flexibility from planned densities.

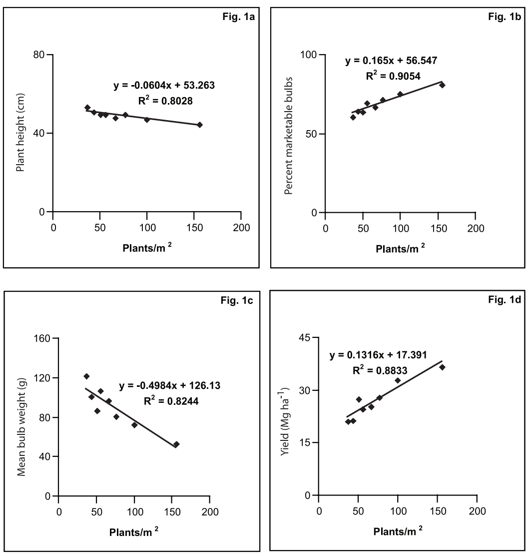

Fig. 1. Plant height, percent marketable bulbs, mean bulb weight and bulb yield as affected by various densities.

Source: Kanton et al., (2002)

Influence of transplanting age on bulb yield and yield components of onion (*Allium cepa L.*).

One cause of low yields of onion is the lack of an optimal transplanting age. Brewster (1994) reported that the transplanting of onion is still the most widely adopted practice in onion production despite development and improvement of direct sowing.

Despite the interest raised by olericulturists and agronomists, the effect of transplant age on crop yield in the literature is sparse (Vavrina, 2002). Brewster (1994) reported that onions grown from transplants in eastern England consistently produced bulb yields of 45 t ha^{-1}, which are harvested two weeks earlier than direct sown onions. Wien (1997) stated that transplanting is a common practice used with small-seeded vegetables, particularly those that are slow or difficult to germinate or may require special conditions. Salter (1985) argued that transplanting enables more control of plant population and spacing, and also maximises the use of expensive seed better than does direct seeding. Oladiram and Sangodele (1996) reported significant ($p<0.05$) effects of transplant age, cultivar and transplant age x cultivar interaction on onion yield.

Much of the work done on transplanting of onion in the temperate regions has been done in special containers in controlled conditions. By contrast no fieldwork has been done on transplanting of onion under field conditions, which small-scale farmers in the warmer regions practice. This work was therefore devoted to establishing under field conditions the most optimal age to transplant onion in Ghana.

Transplants from 30- and 40-day-old matured earlier than those derived from 20-day-old transplants. There are economic advantages associated with earliness in onion production in Ghana, as consumers are usually willing to pay higher premium for early onion. The age of transplants affected all the agronomic variables that were studied. The tallest plants were produced when up to 40-day-old seedlings were used (Fig. 2a). These plants produced bulbs that were taller, wider and heavier compared to the other transplants. Harvest index decreased as transplant age was greater than 40 days (Fig. 2c). Bulb yields from transplants from 20- to 40-day-old transplants were generally similar, and were higher than yields for plants developed from transplants that were older than 40 days. There was a significant ($p<0.05$) correlation between yield and mean bulb weight, bulb diameter and harvest index.

A farmer evaluation indicated that ten of the producers preferred using 30-day-old transplants, 8 preferred 40-day-old transplants with the remaining 2 farmers equally divided between 20- and 50-day-old transplants. Farmer preference of one treatment over the other was influenced greatly by bulb yield and size (*Kanton et al*., 2003).

The higher yields associated with plants developed from younger transplants could be ascribed to better plant growth as depicted in taller and more leafy plants coupled with superior bulb dimensions obtained for younger transplants compared to their older counterparts. Younger transplants seemed more efficient in their conversion of assimilates into harvestable parts than their older counterparts as evidenced by their greater harvest indices compared to their older compatriots. NeSmith (1993) contended that if transplants were delayed past the optimal time in which they are making active growth, then growth and after transplanting and yield would be sacrificed.

The results of the present study thus confirm those of earlier workers, that the age of onion transplant significantly affects onion growth and yield as observed by Oladiram and Sangodele (1996). From the above results the optimal transplanting age for Bawku red is between 20 to 40 days after transplanting. However there is the need to confirm this transplanting age for other onion cultivars across the country.

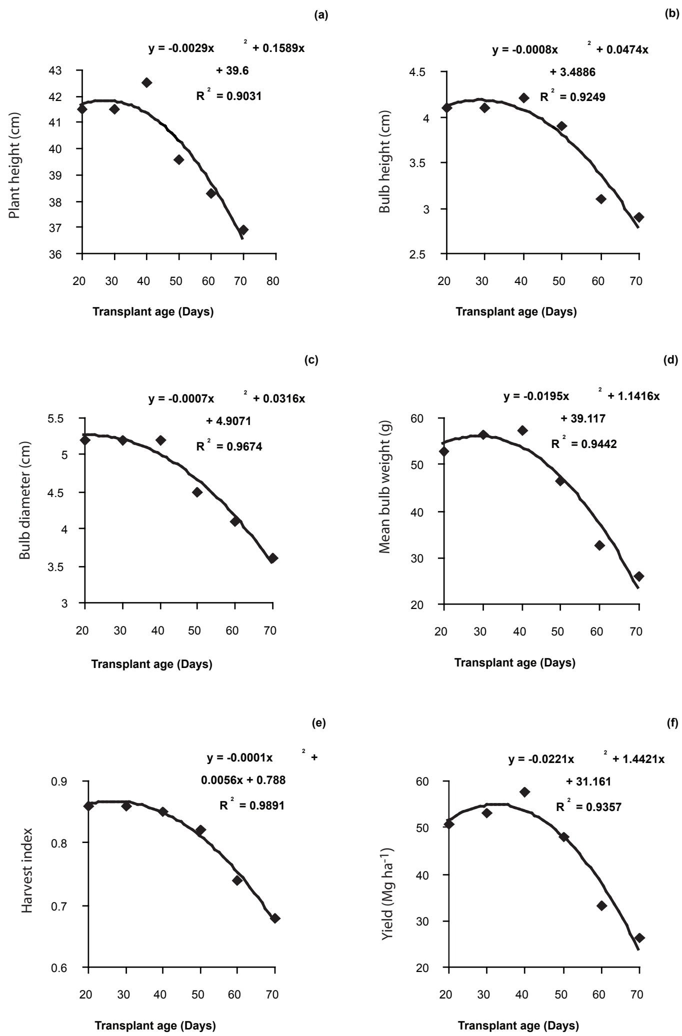

Fig. 2. Influence of transplanting age on bulb yield and yield components of onion (Allium cepa L.) in northern Ghana.
Source: Kanton et al., (2003)

Irrigation schedule affects onion (*Allium cepa L.*) growth, development and yield.

Irrigation water is one of the most important limiting factors for onion cultivation in Ghana. Dams, wells and dugouts remain the main source of irrigation water. Scheduling irrigation according to crop water requirement can be based on Cumulative Pan Evaporation (CPE) and availability of irrigation water (IW). Based on this approach, scheduling irrigation at an IW/CPE ratio between 1.2 and 1.5 maintained a soil moisture regime optimum for onion growth (Palled et al., 1988; Rana, 1989; Partel et al., 1992). As not all growth stages of onion are equally affected by moisture stress, Parashar (1976) and Hedge (1986) reported that bulb formation and enlargement stages 60 to 100 days after transplanting is the most important period for moisture demand and any stress at these stages will cause drastic reductions in bulb yield. Jones and Mann (1963) reported that delayed irrigation resulted in lower bulb yields. The objective of this study was to determine the most optimal irrigation interval for increased onion production in view of the limited irrigation water resources available to growers during the growing season.

Irrigation regime significantly ($p<0.05$) influenced onion height, foliage mean weight, bulb height, diameter, weight and yield (Table 2). Bulbs from plants that were irrigated daily in the morning and in the morning and evening had the tallest bulbs. Irrigation onion plants Morning and evening daily (MED) and morning daily (MD) gave significantly ($p<0.05$) greater mean foliage weight than Morning evening alternate days (MEAD), Morning alternate days (MAD), or Evening alternate days (EAD). The highest mean foliage weight of 1.78 kg plot^{-1} was obtained when onion was irrigated MED. When irrigated MED significantly ($p<0.05$) wider bulbs were obtained compared to MEAD, EAD or MAD (Table 2). The greatest bulb yield (39.8 Mt ha^{-1}) was from plants receiving the MED, followed by closely by MD. The farmers who collaborated in the study preferred irrigating their onion once daily every morning (54.5%) followed by those who preferred once every evening.

As irrigation intervals increased plant height decreased significantly ($p<0.05$). Irrigating onion morning and evening, morning daily or evening daily produced significantly taller plants compared to other treatments; this might be due to moisture stress experienced by increased intervals of irrigation at vegetative and reproductive growth stages. These results confirm those of Babalad and Kulkarni (1987) who reported greater plant height, number of leaves, dry matter and leaf area index at higher cumulative pan evaporation irrigation treatments. Kratlay et al., (1990) reported increased marketable onion yield

Table 2: Onion plant height, mean foliage weight, bulb characteristics and yield as affected by irrigation intervals

Irrigation schedule	Plant height (cm)	Foliage dry weight (kg)	Bulb height (cm)	Bulb diameter (cm)	Bulb weight (g)	Bulb yield (Mt ha^{-1})
MED	39.05a	1.78a	4.2ab	4.4a	32.0ab	39.8a
MD	38.90a	1.74a	4.4a	4.3ab	32.1a	38.6a
ED	39.36a	1.60ab	3.8bc	4.1ab	26.4bc	32.2b
MEAD	34.86b	1.46bc	3.3c	3.8bc	27.6abc	28.8bc
MAD	34.90b	1.38bc	3.6abc	3.9bc	26.7abc	29.1bc
EAD	33.88b	1.32c	3.4c	3.5c	22.6c	24.9c
Mean	36.82	1.55	3.77	3.98	27.89	32.2
CV (%)	14.2	24.3	22.85	18.69	32.65	29.18

Means in a column followed by different superscript (s) are significantly ($p<0.05$) different. MED = Morning evening daily, MD = Morning daily, ED = Evening daily, MEAD = Morning evening alternate days, MAD = Morning alternate days, EAD = Evening alternate days.

Source: Kanton et al., (2003)

Response of cowpea to leaf harvesting and detopping in Northern Ghana

Cowpea (Vigna unguiculata (L) Walp.) is very important in the farming systems of Africa. Besides its seed, the young tender leaves of cowpea are consumed as a vegetable crop by a large population in several African and Asian countries (Barret, 1990). Cowpea leaves rank third or fourth among the leafy vegetables in Africa. (Barret, 1990). Cowpea leaves have also been recommended as favourable candidate for the Controlled Ecological Life Support System (CELSS) programme of the national Aeronautical and Space Administration (Neilsen et al., 1997, and Ohler et al., 1996). In Northern Ghana, particularly in the Upper West Region two types of cowpeas are cultivated; the early and late maturing varieties are usually cultivated. After plant establishment, women harvest the tender leaves for the preparation of soup and other dietary preparations to sustain the family particularly during the hunger period from May to June. A study was conducted to investigate the effects of leaf harvesting and detopping on seed yield of two cowpea cultivars.

Leaf harvesting and detopping delayed flowering for both cowpea cultivars evaluated, however there were no significant differences in number of days taken to attain 50% flowering due to the treatment effects except for Bengpla. The control the local cowpea cultivar 'Dasimah' were shorter compared to the two improved varieties with Bengpla producing the tallest plants at flowering. Leaf picking caused a reduction in all cultivars, Ayiyi – 8%, Dasimah – 20% and Bengpla 40%. A combination of leaf picking and detopping caused a significant reduction in the height of Dasimah and Bengpla, but that of reduction was not significant for Ayiyi (Table 3). Leaf picking and detopping caused reduction in plant height of Ayiyi – 17%, Dasimah – 74% and Bengpla – 79% compared to their respective Controls, suggesting that Ayiyi was less susceptible to leaf picking and detopping compared to Bengpla and Dasimah. Leaf picking resulted in reduction in pod number per plant by 4 and 8 % respectively for Dasimah and Bengpla. However the number of pods per plant of Ayiyi was increased by 9% due to leaf picking. A combination of leaf picking and detopping resulted in an increase in pod number per plant of 38% for Dasimah and 19% for Ayiyi. By contrast a combination of leaf picking and detopping caused a 12% reduction in pod number per plant. The results of the current study are quite fascinating, as a combination of leaf picking and detopping resulted in an increase in number of pods per plant in Dasimah the local variety and Ayiyi one of the improved varieties. However a combination of both leaf picking and detopping is not suitable for Bengpla as it caused a reduction in pod number plant^{-1}. In the literature there are contradictory results from leaf picking, whereas some workers have reported yield losses of up to 13-45% due to leaf picking notably Adu-Dapaah (1997). On the contrary Imungi and Porter (1983) and Akundabwuni *et al*. (1993) found that within limits, cowpea leaves could be harvested without any detrimental effect on seed yield. Since cowpea yields were more than one tonne for the treatment plots, which is in consonance with those reported by Adu-Dappah (1997) when cowpea leaves were picked for three of four times was about one tonne. Considering the important role that cowpea leaves continues to play in substituting or supplementing other leafy vegetables particularly of the poor and vulnerable in society such as women and children is very crucial. This study has revealed that there is the need to screen the wide range of new varieties that are continually released or undergoing breeding needs to be evaluated for their cowpea leaf potential for human consumption since cowpea leaves are both cheap and readily available than most leafy vegetables.

Table 3: The effect of leaf picking (LP) and detopping (DT) on yield and yield components of three cowpea cultivars.

Variety	Treatment	Days to 50% bloom	Plant height at flowering (cm)	Branches plant^{-1} at maturity	Pod plant^{-1}	Seed yield plant^{-1} (g)	Seed yield t ha^{-1}
Dasimah (Local)	Control	34.3a	26.6a	3.9a	16.0a	19.6a	1.7a
	Leaf picking	35.7a	21.3ab	4.4a	15.3a	16.6a	1.4a
	Leaf picking + detopping	36.3a	7.0c	4.6a	22.0a	19.3a	1.6a
Ayiyi	Control	42.3a	41.7a	3.6a	18.3a	25.6a	2.1a
	Leaf picking	42.3a	38.3a	3.7a	20.0a	22.8a	1.9a
	Leaf picking + detopping	43.3a	34.3a	4.7a	21.7a	21.9a	1.8a
Bengpla	Control	35.0b	44.1a	3.2a	11.7a	17.7a	1.5a
	Leaf picking	35.3b	26.6b	3.4a	10.7a	15.8a	1.3a
	Leaf picking + detopping	38.3a	9.2c	3.8a	10.3a	12.8a	1.1a

Means within a column followed by the same letter are no significantly ($p<0.05$) different by Duncan's

Multiple Range Test Source: Bayorbor et al. (2003)

Conclusion

From the above it review it can be concluded that very little work on dry season vegetable production has been carried out in Ghana and particularly so with protection and storage research which is rather scant in the literature. Also much of the research work done seem to concentrate on bulb onions, tomatoes and pepper with little work on leafy vegetables which constitute a major source of food for the poor and vulnerable in the country. There is also an ever increasing demand for both indigenous and exotic vegetable from Ghana by the European and American markets, which has led to the establishment of the Export Development Investment Fund (EDIF) with funding from the European Union (EU), this suggests that if the export drive of the country is to become competitive then there is the urgent need to intensify research into vegetables so as to increase both their production and productivity thereby providing jobs for the teeming unemployed youth who thronged the cities for non existent white colour jobs. There is the need to re-direct efforts in vegetable research in the country, with a view to expanding to cover the little researched vegetable crops. Generally speaking the economic returns from dry season vegetable production far out weigh those obtained from arable crops such as millet and sorghum grown mainly in the rainy season, as reported in a survey carried out in 1993 by the Upper East Region Farming Systems Research Team (UER-FSRG), suggesting that more research attention needs to be paid to vegetable crop research.

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Chapter 17

Way forward and future perspectives

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Abstract

In the Volta Basin the majority of the population is resource poor smallholders who depend on rainfed agriculture for their livelihoods. However, because of erratic and low rainfall rainfed agriculture is a very risky business. Agriculture consumes about 70 – 90% of water use. Therefore, to meet the needs of a growing population, more food must be produced using less water. In a broader sense, improving water productivity will mean getting more value from every drop used for either crops, fish, forests or livestock while maintaining or improving ecosystems services. In the past, international and national agricultural research systems have developed high-yielding cereal and legume cultivars that respond to different rainfall regimes. However, although it is known that an integrated approach to water, crop and nutrient management is essential for increasing and stabilizing crop production and optimizing inputs use, there is a dearth of empirical studies on such interactions. A win-win situation can occur when a systems research integrates germplasm, crop, nutrient, soil and water management, with explicit focus to empowering farmers and rural communities to take advantage of market opportunities to raise their incomes and invest in better management of their resources. New tools such Geographical Information Systems (GIS) and models can be very useful in facilitating the analysis of these integrated systems. On the other hand, participatory research approaches have been found very effective in enhancing the adoption of technologies, empowering rural communities and promoting equity. It is in this context and as a response to a call for proposals that a project proposal was submitted to the Challenge Program on Water and Food (CPWF) for funding. The project is designed to address the major constraints that are encountered by small-scale resource-poor farmers in the Volta Basin, who rely on rain fed agriculture for their livelihoods, using a systems approach that integrates water use efficiency, soil and nutrient management, and improved germplasm together with market opportunity identification and building rural communities capacity. The biophysical and socio-economic characteristics of the Volta Basin are described extensively in chapter 1. Chapters 2 to 16 contain the syntheses of the research and development work that was conducted, over the years, by various research organizations in Burkina Faso and Ghana that are the participating countries in this project. From this information, constraints to agricultural productivity and opportunities for complementary research were identified.

Key Words: *Rainfed agriculture, water productivity, systems research, soil and nutrient management, Participatory research approach*

Résumé

Dans le Bassin de la Volta la majorité de la population est constituée des petits producteurs qui dependent de l' agriculture pluviale pour leur subsistence. Cependant à cause de la faible pluviométrie et de son caractère aléatoire, l' agriculture pluviale est une entreprise à hautes risques. L' agriculture consomme approximativement 70 à 90 % de l' eau utilisée. Ainsi, pour satisfaire les besoins de la population grandissante, plus de nourriture doit être poduite en utilisant moins d' eau. Dans un sens global, améliorer la productivité de l' eau signifiera l' obtention de plus de valeur pour chaque goutte d' eau utilisée pour soit les cultures, les poissons, les forêts ou l' élévage tout en maintenant ou en améliorant les services produits par les écosystèmes. Dans le passé les systèmes internationaux et nationaux de recherche ont développé des cultivars de céréales et des légumineuses à hauts rendements repondant aux differents régimes pluviometriques. Cependant, bien qu' il soit connu qu' une approche intégrée à la gestion de l' eau, des cultures et des nutriments soit nécessaire pour améliorer et stabiliser la production et optimiser l' utilisation des intrants., il manque des études empiriques sur de telles interactions. Une situation de « win-win ou de reussite» peut survenir quand une recherche des systèmes intègre la gestion du germplasme, des cultures, des nutriments, du sol, et de l' eau, avec un accent sur le renforcement des producteurs et des communautés rurales pour exploiter les opportunités du marché afin d' augmenter leurs revenus et investir dans une meilleure gestion des ressources. Des nouveaux outils tels que les systèmes d' information geographique (SIG) et les modèles peuvent être très utiles pour faciliter l' analyse des systèmes intégrés. D' autre part, les approches participatives de recherche sont considérées très efficaces à accélerer l' adoption des technologies, renforcer les communautés rurales et promouvoir l' équité. C' est dans ce contexte et en reponse à l' appel à propositions que cette proposition de projet a été soumise au « Challenge Program on Water and Food » pour financement. Le projet a été conçu pour aborder les contraintes majeures auxquelles font face les petits et pauvres producteurs dans le Bassin de la Volta qui dependent de l' agriculture d' hivernage pour leur subsistence, en utilisant l' approche des systèmes qui intègre l' utilisation éfficiente de l' eau, la gestion de sol et des nutriments, et le germplasme amélioré en combinaison avec l' identification des opportunités du marché et le renforcement de la capacité des communautés rurales. Les caractéristiques biophysiques et socio-économiques du Bassin de la Volta sont décrites extensivement dans le chapitre 1. Chapitres 2 à 16 contiennent les synthèses des travaux de la recherche et du développement qui ont été conduits au cours des années par les differentes organizations de recherche au Burkina Faso et au Ghana qui font partie de ce projet. A partir de cette information, les contraintes à la productivité agricole et des opportunités pour une recherche complementaire ont été identifiées.

Mots Clés: *Agriculture pluviale, productivité de l' eau, recherche systèmes, gestion de sol et des nutriments, approche participative de recherche*

Rationale

The biophysical and socio-economic characteristics of the Volta Basin are described extensively in chapter 1. Chapters 2 to 16 contain the syntheses of the research and development work that was conducted, over the years, by various research organizations in Burkina Faso and Ghana that are the participating countries in this project. From this information, constraints to agricultural productivity and opportunities for complementary research were identified.

The majority of the population in the basin is resource poor smallholders who rely on rainfed agriculture for their livelihoods. However, the average rainfall of 1000 mm per year, which seems to be enough for crop production in the region, is quite variable, (Andreini et al., 2000), thereby making rainfed agriculture a risky enterprise. The distribution of rain over the growing season has also been noted to be another bottleneck in agricultural production. Especially the onset of the rainy season is very unreliable and the frequent periods of drought (10-20 days) within the season cause significant crop damage (Adiku et al., 1997). In addition, there has been a decrease in rainfall in most of the region since the 1960's when compared to the 20th century average (Nicholson, 1998).

Water scarcity is one of the most pressing issues facing humanity today. Provision of sufficient water is necessary for human health and poverty reduction. However, water quality and availability are highly variable and typically, the most extreme shortages are experienced by those least able to cope with them; the most impoverished inhabitants of developing countries. Water for agriculture consumes 70 – 90% of water use. To meet the needs of a growing population, more food must be produced using less water. In addition to the erratic, low and unpredictable rainfall over the years, other factors contributing to water becoming a scarce resource in the Volta basin are the increasing population and livestock pressure, and the growing competition over the use of water for generating hydroelectricity.

At the macro-level, a water management issue emerges. Development of water resources for agriculture is needed to develop the poorer rural societies of Ghana and Burkina Faso (Giesen et al., 2000) in the Volta Basin. Such development will have a yet unknown downstream consequence on the availability of water for hydropower. In turn, reduced hydropower generation threatens industrial development in the South. Upstream, Burkina Faso is more interested in irrigation development since they do not profit from hydropower generation and have no alternatives but agriculture. On the other hand, Ghana in the downstream is more interested in electricity as suggested by the on-going preparation for the construction of a third large dam in Bui gorge.

In the entire Volta Basin, thus, food security is under threat due to the low water availability, increasing soil degradation and the dwindling farm sizes (Steiner and Rockstrom, 2003). Crop failure has not been the consequence of only low rainfall but also due to the effect of soil degradation caused by inappropriate management practices like plowing and intensive hoeing causing surface crusting, soil compaction, decrease in soil organic matter and hard-pan formation. All these have contributed to the inefficient use of the precious water available.

Declining water quantity and quality has become a critical limiting factor to agricultural productivity. Water use efficiency holds the key to improving agricultural and livestock productivity in the Volta Basin. The solution to the water crisis could be found in how water is developed and managed to improve its productivity in agriculture. In a broader sense, improving water productivity will mean getting more value from every drop used for either crops, fish, forests or livestock while maintaining or improving ecosystems services. More importantly past research have shown that only 10% of the rainwater is used by the crop, the majority of it being lost to evaporation

In the past, international and national agricultural research systems have developed high-yielding cereal and legume varieties that respond to different rainfall regimes. For example, ICRISAT and its National Agricultural Research and Extension Systems (NARES) partners have developed and promoted improved varieties of sorghum, millet and groundnut and soil management technologies adapted to the semi-arid conditions (Bationo et al., 1998; Bationo and Ntare, 2000; Tabo, 1998). Similarly, the Center for Development Research and the International Water Management Institute are currently developing decision support tools to assist in the management of water in the Volta.

However, although it is known that an integrated approach to water, crop and nutrient management is essential for increasing and stabilizing crop production and optimizing inputs use, there is a dearth of empirical studies on such interactions. Furthermore, majority of research has been conducted with little participation of farmers and rural communities who are the ultimate users and beneficiaries of research results. This has largely limited the adoption of agricultural technologies by small scale farmers, especially women who constitute the majortity of farming population. We now know that farmers and rural communities are searching for new ways to intensify and diversify their systems to meet their food security needs as well as generating income, and seize upcoming market opportunities. Yet, until recently, agricultural research has not been effective in responding to these challenges. A win-win situation can occur when a systems research integrates germplasm, crop, nutrient, soil and water management, with explicit focus to empowering farmers and rural communities to take advantage of market opportunities to raise their incomes and invest in better management of their resources. New tools such Geographical Information Systems (GIS) and models can be very useful in faciliting the analysis of these integrated systems. The DSSAT-CENTURY (Decision Support for Agro technology Transfer) cropping systems models enables the analysis of how different soil, climatic and land management strategies affect the yield of a range of crops (Gijsman et al., 2002). On the other hand, participatory research approaches have been found very effective in enhancing the adoption of technologies, empowering rural communities and promoting equity.

The project is designed to address the major constraints that are encountered by small-scale resource-poor farmers in the Volta Basin, who rely on rain fed agriculture for their livelihoods. Our overall research hypothesis is that using a systems approach that integrates water use efficiency, soil and nutrient management, and improved germplasm together with market opportunity identification and building rural communities capacity will result in significant benefits to the rural poor and the environment.

It is in this context and as a response to a call for proposals that a project proposal was submitted to the Challenge Program on Water and Food (CPWF) for funding. CPWF is an international, multi-institutional research initiative with a strong emphasis on north-south and south-south partnerships. The initiative brings together research scientists, development specialists, and river basin communities in Africa, Asia and Latin America to create and disseminate international public goods (IPGs) that improve the productivity of water in river basins in ways that are pro-poor, gender equitable and environmentally sustainable.

Goal

The overall goal of this project is to reduce poverty and improve food security, income and livelihoods of small-scale resource-poor farmers in the Volta Basin through the development and adoption of technology options and market institutional innovations for more efficient use of water and nutrients.

Specific Objectives

The project is designed to address the major constraints that are encountered by small-scale resource-poor farmers in the Volta Basin who rely on rain-fed agriculture for their livelihood. The specific objectives are:

1. To develop, evaluate and adapt, in partnership with farmers, integrated technology options that improve water and nutrient use efficiencies and increase crop productivity in the Volta Basin.
2. To develop and validate methodologies, approaches and modern tools (GIS, models, farmer participatory approaches) for evaluating and promoting promising water, nutrient and crop management technology options.
3. To improve market opportunities for small holder farmers and identify market institutional innovations that provide incentives for the adoption of improved water, nutrient and crop management technologies.
4. To build the capacities of farmers and rural communities to make effective demands to research and development organizations, and influence policies that promote the adoption of sustainable water and nutrient use technologies.
5. To promote and scale up and out ‘best bet’ crop, water, and nutrient management strategies in the Volta Basin through more efficient information, methodology and technology dissemination mechanisms.

Methodology

The methodology of the project will draw on and apply principles and approaches of Integrated Natural Resources Management (INRM). The INRM paradigm provides a significant opportunity to conduct research in a different and innovative way, integrating systems research perspectives including germplasm, crop, nutrient and water management together with a focus on marketing, policy and participatory approaches that have the potential to empower farmers.

This is a multi-institutional and multi-disciplinary project that is designed in such a way that the comparative advantage of each institution and team member is taken into account. The team comprises soil scientists, agronomists, physiologists, rural sociologist, agroeconomists, systems modeler, GIS specialists, agroclimatologists, hydrologists, and extensionists from various institutions. All the aspects of the project including the biophysical, socio-economics, training, adoption and impact are covered.

The proposed institutions have on-going projects that address some aspects of the constraints that this project is aiming at tackling. There is a mix of expertise in these various institutions ranging from natural resource management, crop improvement, training, modeling, GIS, rural sociology and socio-economics to technology transfer. These institutions have the necessary logistics and equipment to carry out the work

The lead institution, ICRISAT is active in the region where this project will be implemented. ICRISAT is a convening center for the Desert Margins Program (DMP) and has already developed a consortium that is well placed to backstop the activities of this project. The DMP addresses most of the research topics in the Volta Basin, particularly those dealing with soil, water and nutrient management and land degradation.

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The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a nonprofit, non-political, international organization that does innovative agricultural research and capacity building for sustainable development with a wide array of partners across the globe. ICRISAT also shares information and knowledge through capacity building, publications and information and communication technologies (ICTs). Established in 1972, it is one of 15 Centers supported by the Consultative Group on International Agricultural Research (CGIAR). It belongs to the Alliance of Future Harvest Centers of the CGIAR.

ICRISAT's vision is the improved well-being of the poor of the semi-arid tropics. Its mission is to reduce poverty, increase agricultural productivity, enhance food and nutritional security and protect the environment of the semi-arid tropics by helping empower 600 million poor people through science with a human face and partnership-based research.

To achieve its vision, mission and goal, ICRISAT adopts Integrated Genetic and Natural Resource Management (IGNRM) as its overall research strategy. Through IGNRM, ICRISAT will continue to develop and promote improved crop varieties and sustainable management practices, enabling farmers to improve household food security and meet global market demand.

The CGIAR Challenge Program on Water and Food (CPWF)

The CGIAR Challenge Program on Water and Food (CPWF) is an international, multi-institutional research initiative with a strong emphasis on north-south and south-south partnerships. The initiative brings together research scientists, development specialists, and river basin communities in Africa, Asia and Latin America to create and disseminate international public goods (IPGs) that improve the productivity of water in river basins in ways that are pro-poor, gender equitable and environmentally sustainable.

CPWF practices research for development. Ongoing research work exemplifies this emphasis, and illustrates the Challenge Program's mix of site-specificity, scaling up to the basin level, and the production of international public goods. Thus, CPWF funds and conducts research that is a mixture of basic, applied and adaptive research linked to dissemination of results.

The Challenge Program works towards achieving:

- Food security for all at household level
- Poverty alleviation through increased sustainable livelihoods in rural and peri-urban areas
- Improved health through better nutrition, lower agriculture–related pollution and reduced water-related diseases
- Environmental security through improved water quality as well as maintenance of water-related ecosystems and biodiversity

The CPWF is a widely dispersed program. The senior scientists who lead the five thematic areas of research, are located in the CGIAR centres of IRRI, CIAT, WorldFish, IWMI and IFPRI. Basin Coordinators are based in the institution representing the nine benchmark river basins. Management Team members are based in their home institutes. The Secretariat is based in Sri Lanka, hosted by the International Water Management Institute (IWMI). IWMI is a member of the CPWF Consortium IWMI is the 'lead center' on behalf of the CPWF Consortium members, including as legal representative. A representative of IWMI chairs the CPWF Steering Committee (CSC). As the program operates under a Joint Venture Agreement, the CPWF does not enjoy legal status. Therefore CPWF contracts are signed by IWMI on behalf of the CPWF. The secretariat operates as an autonomous program, is independent of the Consortium members, reports to the CSC and prepares recommendations on issues of policy, research planning and annual workplans and budgets. The secretariat coordinates the entire process of identifying research priorities and the selection process for contracting research projects to ensure neutrality and transparency of operations. This process is explained later in these guidelines. An important aspect of the process is the selection and contracting of independent, senior scientists to assess submissions, whose appointment is approved by an external CPWF 'Expert Panel' that has no reporting obligations to the CSC..

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