OXFAM AMERICA
Research Report

MALI AGRICULTURAL PILOT

SOIL BASELINE AND BACKGROUND RESEARCH

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This is a report of Oxfam America's Agriculture Pilot. The program has been operating in Mali since December 2011.

The research project was commissioned by Sophie Romana, Director, Community Finance with funding from Oxfam America. The research process was managed by Janina Matuszeski, PhD, Senior Research Coordinator from Oxfam America, from October 2012 to February 2013. The research was carried out by Dr. Daouda Sidibé through a competitive process and reflects the findings as reported by him in validation with stakeholders.

For additional information regarding the evaluation Terms of Reference, please refer to the report appendices.

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PREFACE

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LIST OF ABBREVIATIONS AND ACRONYMS

AGRA	Alliance for a Green Revolution in Africa
CMDT	Compagnie Malienne de Développement du textile
CEC	Cation Exchange Capacity
CMDT	Compagnie Malienne de Textile
DNEF	Direction National des Eaux et Forets
DNCN	Direction National de Conservation de la Nature
FAO	Food and Agriculture Organization
ICRISAT	International Crops Research Institute for Semi-arid and Tropic
IER	Institut d'Economie Rurale
IMF	International Monetary Fund
IPR-IFRA	Institut Polytechnique Rural de Formation et de Recherche Appliquée
MA	Ministère de l'Agriculture
MDG	Millenium Development Goals
MDR	Ministère du Développement Rural
MEME	Ministère de l'Environnement des Mines et de l'Energie
LaboSEP	Laboratoire Sol-Eau-Plante
LOA	Loi d'Orientation Agricole
NTFP	Non Timber Forest Product
PIRL	Projet d'Inventaire des Ressources Ligneuses
RGPH	Recensement Général de la Population et de l'Habitat
SFC	Saving for Change
UEMOA	West African Economic and Monetary Union

UNESCO	United Nations Educational, Scientific and Cultural Organization
UNDP	United Nations Development Program

EXECUTIVE SUMMARY

Common agricultural practice in West Africa involves alternating crop cultivation for 10-12 years and thereafter leaving the field to rest (fallow) for 10-15 years (Kidron et al. 2010). With increasing population pressure and growing demand for food on the one hand, and the lack of unexploited lands on the other, soils undergo fast degradation. In the semi-arid zone of West Africa, soil degradation due to water erosion is a serious threat to sustainable agricultural land use as it affects soil productivity (Laflen and Roose, 1998). The traditional parklands systems, which are the main providers of food, income and environmental service, are rapidly degrading (Bayala et al. 2011). The decrease in the fallow period on the one hand and the reduction in reserve soils on the other hand may pose a real threat to soil quality in Mali (Kidron et al. 2010).

Alleviating erosion-induced loss will require the development and adoption of land use systems that are capable of replenishing or maintaining the nutrient status of the soil in addition to controlling erosion (Sanchez et al. 1997; Zougmoré et al. 2009). However, there is a growing number of cases which document success in soil fertility and water availability improvement (Bayala, 2011). Consequently, there is a need to better understand the drivers of such successes and the circumstances in which they work, to serve as a basis for future actions.

Oxfam America's Saving for Change (SfC) program is designed to serve rural poor. SfC is based on the knowledge that villagers are not "too poor to save". Everyone must save to subsist between the harvest and the next planting. Oxfam America currently supports Saving for Change groups in Mali (405,000 women). Program goals of Oxfam America include increased food security, lower vulnerability to crises, and overall improved livelihoods for members and their families. Within these contexts, in 2010, interest by SfC' women members in learning new gardening and agricultural techniques, combined with the availability of soil fertility expertise led Oxfam America to create an agricultural pilot covering 20 villages. Women and men were trained in various soil conservation measures, especially the planting of particular species of trees and bushes to help with soil fertility. A short-cycle cow pea variety was also introduced in these villages. The agricultural pilot built on the solidarity and resources of the SfC women's groups.

There is a need to further understand prior research in Mali on soil building, conservation and re-fertilization techniques, including which techniques have proved most promising. A soil baseline in the 20 pilot villages will allow us to track how soil fertility changes over subsequent years. In each of the pilot villages, women have been given a collective field on which to try agricultural

techniques. Pilot villages are located in the circles of Sikasso, Koutiala, Bougouni and Koulikoro.

Based on these research needs, SfC program of Oxfam America launched these studies to document and summarize prior research on soil fertility and water availability in west Africa and Mali, to determine the current level of soil fertility and water retention in experimental plots in the 20 agricultural pilot villages and to illicit stakeholders (farmers, researchers, NGOs and state agricultural technicians) knowledge on soil fertility status and water availability in agricultural production systems.

A literature review was performed on soil fertility and water availability state in West African countries and Mali. The literature review included also available soil and water conservation technologies. The results of this review indicated that soil fertility and water availability are major problems in West Africa in general and particularly in Mali. According to Zougmoré et al. (2010), land degradation is a major constraint to the sustainability of agricultural systems in semi-arid areas of West Africa. Soils of Sahelian countries have in common a broad expansion of sandy cover and a high presence of iron which is the basis for of large ferruginous and gravelly soils formation on summits and slopes of the toposequence. The presence of armour plate and / or gravel affects the water retention capacity and soil nutrients availability. Clayey soils (kaolinitic type) are found in the lower parts of the toposequence and do not allow a good storage of water and nutrients (Pieri, 1991). Loss of soil productivity due to degradation in Africa since 1950 is estimated at 20% (Dregne 1990; Bationo et al. 2006). In Africa, loss of forests cover exceeded 4 million of ha/year between 2000 and 2005 (Bationo et al. 2006). This loss was mainly due to conversion of forest lands to agriculture. Most African soils are inherently very low in organic carbon (<20 to 30 mg / kg). According to Nandwa (2003), results from long-term soil fertility trials show that even with high levels of organic inputs, losses of up to 0.60 tons of carbon/ha/year in the soil surface layers are common in Africa. Factors such as agro technical changes, socio-economic changes institutional and legislative reforms of agricultural sector have worsened the soil fertility problems in Sahelian countries of West Africa.

Sahelian countries are characterized by a tropical climate with a single rainy season lasting 2-4 months (Sissoko, 1998). Rainfall varies between 100 and 1100 mm per year. Rainfall is characterized by a high variability: total annual rainfall, starting date of the season, duration and distribution during the rainy season.

Water erosion is a serious threat to the sustainability of agricultural land use and it affects soil productivity (Laflen and Roose 1998; Zougmoré et al. 2010). Water erosion is responsible for the negative nutrients and carbon balances in most farming systems in West Africa (Zougmoré et al. 2010) and for the reduction of crop rooting depth (Morgan, 1995). The low soil quality combined with the harsh Sahelian climate leads to a low efficiency of fertilizers (Breman et al. 2001). According to Lal (1997), one of the key conditions to increase soil productivity in the sub-Saharan zone is to ensure effective water infiltration and storage in the soil.

Like all Sahelian countries, there are problems of soil fertility in Mali. The main causes of soil fertility degradation included the expansion of cultivated areas, the migration of livestock southward and the socio-economic situation in Mali.

In order to improve and maintain soil fertility, many strategies (from 1960 to 2013) have been developed by the governments of Mali and some have been implemented. These strategies included the sectoral approach, the national plan for integrated soil fertility management, the sustainable land management (SLM), the microdose fertilization, the rice initiative and the soil fertility map of Mali.

Concerning the availability of water resources in Mali, rainwater constitutes the main water resources of Mali and provides in average 415 billion m3 of water per year. According to the aridity index described by UNESCO (1977), more than 90% of the area of Mali are considered arid and more specifically 47% of lands in Mali are hyper arid. This drought becomes more pronounced due to the reduction of the mean annual rainfall. A comparison between the years 1950s and 2000s reveals downward trend of isohyets from North to South. The rainfall tendency curves of the visited circles indicated a decline in rainfall in these areas from years 90s to 2010s.

The hydrographic system of Mali is mainly composed of three basins: The Niger, Senegal and Volta basins. Problems of degradation of water resources in Mali included domestic pollution, degradation and illegal occupation of river banks, industrial and traditional pollution, deforestation, silting and the pollution related to agricultural activities.

A literature review has been performed to document available soil and water conservation technologies. According to Bationo et al. (1996), these different technologies can be grouped into techniques such as: 1) Soil protection and water conservation; 2) Improvement of land use systems and 3) Adding mineral and organic fertilizers.

Soil protection and water conservation techniques found in the literature included stones rows, mulching, ridging (Ploughing), zaï, half-moons and the contour line management technique.

Improving the land use system refers to hedges (living fences), grass strips, forage sole or improved fallows, assisted natural regeneration (ANR) and crop rotation (association cereals - legumes).

Measures of crop fertilization included crop mineral and organic fertilization. Crop mineral fertilization is based on adding fertilizers such as nitrogen, phosphorus, potassium and trace elements like zinc, boron and sulfur while organic fertilization concerned improved animal parks and incorporation of crop residues and green manure.

Concerning the Gliricidia experimental plots, a soil baseline study was performed in the 20 pilot villages and this will allow us to track how soil fertility changes over subsequent years. The soil analysis focused on the physico-chemical properties: the particle size with 3 fractions (clay, silt, sand), pH (water), pH (KCl), Pf (2.5, 3.0, and 4.2), soil organic matter (C), nitrogen (N), total available phosphorus and available potassium.

The soils have coarse (sandy loam) texture, light and easy to work. Soils are potentially acidic ($\Delta pH > 1$), relatively poor in organic matter and nutrients (especially nitrogen and phosphorus). Therefore it is necessary to properly apply organic and mineral fertilizers as advised by extension services.

The survival rate and the state of Gliricida trees were evaluated one year after plantations. Gliricidia sepium plantation was a success in most of the pilot villages. The percentage of survival reached 100% for some villages. The lower survival rates (14% in one village and 50% in another) are found in Banamba circle.

In the present study, a base line survey was conducted in Koulikoro and Sikasso regions to illicit farmers' knowledge and practices concerning soil fertility and water availability changes over the past 5, 10, 20 years, the impact on yield, soil variability within a village, size and location of plots according to gender, the vulnerability of households to degrading soils, the speed of land degradation and strategies developed or known to men and women to mitigate soil fertility and water availability depletions.

Soil Fertility State in Koulikoro and Sikasso Regions

The results of interview indicated that a high majority of respondents reported that fields' soils are not fertile (84% in Sikasso and 62% in Koulikoro region). Concerning the soil fertility status, a high majority of respondents (100% in Sikasso and 82% in Koulikoro) reported a decline of soil fertility over the past 5, 10 20 and years.

Overexploitation of fields is perceived as the main cause of soil fertility decline (86% of respondents in Sikasso region and 66% in Koulikoro). Soil erosion is perceived as a cause of soil fertility decline by 44 and 22% of respondents in Sikasso and Koulikoro regions respectively. All the respondents reported a decrease in crop production when there is a decline of soil fertility. A high majority of respondents reported that poorer soils are being degraded faster than richer soils and poor households are more vulnerable to soil degradation than richer families.

Soil Fertility Improvement Techniques

97% of the respondents reported that they know about some soil fertility improvement techniques. Among soil improvement techniques, organic manure, mineral fertilizer, composting and tree planting were cited by respondents.

In Koulikoro and Sikasso regions, the majority of farmers (77%) know organic manure as soil improvement technique and it is used by 51% and 50 % of respondents in Koulikoro and Sikasso regions respectively. Mineral fertilizer is known as soil fertility improvement technique by 52% of the respondents. In all the villages surveyed, 72% of the respondents did not know the composting technique. Only 19% of respondents knew tree planting as soil fertility improvement technique. Tree plantation is perceived more in Sikasso (23%) as soil fertility improvement technique than in Koulikoro (14%). The majority of respondents (96%) in the two regions reported that they do not use tree planting as soil fertility improvement technique. Soil fertility improvement techniques such as crop rotation, cereal-legume association, fallowing, parking of animal, crop residues incorporation, ploughing, live fences, parklands, stones rows, controlled natural regeneration were not mentioned by farmers as known techniques.

Water Availability

In response to the question whether wells dries up during the dry season, 90% and 50% of the respondents reported that wells dries up in Koulikoro and Sikasso regions respectively

In response to the question if there are permanent ponds and rivers in their village territory, 99% of the respondents in Koulikoro reported that that there are no permanent rivers and ponds in their region while in Sikasso 52% of respondents reported that there are permanent ponds and rivers in their region. In Sikasso region, 33% of respondent reported that there is sufficient water in the dry season to irrigate gardens and tree plantation while in Koulikoro 51% reported the contrary. The majority of respondents reported a decrease in rainfall availability (70% in Koulikoro and 100% in Sikasso region).

Water Conservation Technique

In response to the question of stone rows as water conservation technique, 88% of the respondents in Koulikoro region knew it while only 48% in Sikasso region knew the technique but the majority of respondents reported that they do not use the technique (99% in Sikasso and 82% in Koulikoro).

Ploughing is known as water conservation technique by 69 and 71% of the respondents in Koulikoro and Sikasso regions respectively but 57% and 47% of them reported that they do not use ploughing as water conservation technique.

Tree planting is known as water conservation technique by 71 and 53% of the respondents in Sikasso and Koulikoro regions respectively but unfortunately they do not use tree planting as water conservation technique.

Fallowing is known by 62% of the respondents in Koulikoro region while in Sikasso, 69% of the respondents did not know fallows as water conservation technique.

Land enclosure, earth bund and organic manure are not known by the majority of respondents as water conservation techniques in Koulikoro and Sikasso regions.

Perceptions of Technical and Scientist Resource Persons on Soil Fertility and Water Availability

A survey was conducted in Bamako district, Koulikoro and Sikasso regions to illicit technical and scientist resource persons knowledge and practices concerning soil fertility and water availability changes over the past 5, 10, 20 years.

Technical services agents, research institutions and non-governmental organizations are unanimous on the fertility degradation in the Koulikoro and Sikasso regions (circles of Sikasso, Bougouni, Koulikoro, Koutiala, Banamba, Kati and Kolokani).

In these areas, soil fertility decline has been observed during the past 5, 10 and 20 years.

The human pressure due to the cultivation of cash crops especially the cotton boom of the years 1990 has largely contributed to land degradation in Koutiala regions.

The causes of soil fertility decline mentioned by the respondents are: overexploitation, erosion, climate change (drought), migration of animals (pasture) from the north to the south, clearing and excessive cutting of wood for fire wood and charcoal production and the non-adoption of erosion control techniques.

A decrease in rainfall during the past 5, 10 and 20 years was reported by the majority of respondents. Agricultural activity is exclusively dependent on rainfall in Koulikoro and Sikasso regions and rain water availability fluctuates within and between years. There are irrigable lowlands in Bougouni and Sikasso zones. Kénédougou basin (Lotio River) can irrigate one million hectares when the depression areas are very well managed according to a NGO official.

The National Agricultural Policy Plan and the Guide of Agricultural Law were elaborated by the Ministry of Agriculture in Mali, but these plans did not get material and financial support from the state.

A hydrology report for Mali can be found at the National Water Headquarter in Bamako. There is a national plan for improving water management in the next 10 years in a document called "Integrated Water Resources Management (GIRE) in Mali.

According to many respondents, in these two regions there are areas of better water availability or better soil fertility. Pre- Guinean and Sudanian zones have still better water availability or better soil fertility (great potential) than arid areas (Sahel and Sahara).

The techniques for improving soil fertility identified by the respondents are: stone rows, tillage, ridge, contour line, live fences (hedgerow), enclosure, composting, organic manure, grass strips, planting trees such as Gliricidia sepium, Piliostigma reticulatum (Niama) and Faidherbia albida (Balazan), fallowing, crop rotation, earth bund, tillage at the end of agricultural cycle, improved clearing, assisted natural regeneration (RNA), liming, green manure and agroforestry parklands (Balazan, Vitellaria paradoxa (Karité).

Among the cited techniques, tillage, tree planting, organic manure, assisted natural regeneration, fallow, contour line, green manure, grass strips and bunds are the low-cost techniques that can be spread through education.

Field contour with clay, Rehabilitation of large diameter wells, drilling, small dams, rainwater harvesting technology, stone rows, grass strips, earth bunds, tree planting, assisted natural regeneration, lowlands water management, pastoral ponds management and contour lines have been identified as techniques to improve water availability for agricultural activities.

Tree planting [Gliricidia sepium, Tephrosia voguelii and Piliostigma reticulatum (Niama)], composting, assisted natural regeneration and hedgerows have been cited as low-cost techniques that can be spread through education.

INTRODUCTION

BACKRGOUND AND PROBLEM DEFINITION OF PRESENT STUDY

Hundreds of millions of people in Asia, Africa and Latin America live on one dollar a day or less. During the last several decades microfinance institutions have been a major positive force in giving millions of poorer people access to credit. However, rural areas are disadvantaged in terms of coverage by microfinance institutions; the costs of delivery are high and the demand for loans large enough to turn a profit is low. Consequently, less than a fifth of the rural poor have access to savings or other financial services that can help them increase their financial security and improve their lives.

Oxfam America's Saving for Change (SfC) program is designed to serve these rural poor. SfC is based on the knowledge that villagers are not "too poor to save" – everyone must save to subsist between the harvest and the next planting. But savings kept at home ("under the mattress," in jewelry, animals, or with traditional savings and lending groups) can lose value or be stolen. Money at home can also be easily spent and many villagers would prefer to "tie their own hands" with savings products that make it difficult to spend their money.

Program goals of Oxfam America include increased food security, lower vulnerability to crises, and overall improved livelihoods for members and their families. Oxfam America currently supports Saving for Change groups in Mali (405,000 women), El Salvador (15,000 women and youths), Guatemala (4,500 women), Cambodia (76,000 women and men), and Senegal (49,000 women).

Common agricultural practice in West Africa involves alternating crop cultivation for 10–12 years and thereafter leaving the field to rest (fallow) for 10–15 years (Kidron et al. 2010). With increasing population pressure and growing demand for food on the one hand, and the lack of unexploited lands on the other, soils undergo fast degradation. Soil degradation is a major global issue because of its adverse impact on the sustainability of agricultural production (Zougmoré et al. 2009). In the semi-arid zone of West Africa, soil degradation due to water erosion is a serious threat to sustainable agricultural land use as it affects soil productivity (Laflen and Roose, 1998). In this region, erosion is worsened by poor soil and crop managements, which adversely affect soil resilience (Lal, 1998). Indeed, erosion by run-off water is responsible for negative nutrient and carbon balances in most farming systems in West Africa (Zougmoré et al. 2009) and for the reduction of crop rooting depth (Morgan, 1995). The decrease in the fallow period on the one hand and the reduction in reserve soils on the other hand may pose a real threat to soil quality in Mali (Kidron et al. 2010).

Alleviating erosion-induced loss will require the development and adoption of land use systems that are capable of replenishing or maintaining the nutrient status of the soil in addition to controlling erosion (Sanchez et al. 1997; Zougmoré et al. 2009).

In 2010, interest by SfC' women members in learning new gardening and agricultural techniques, combined with the availability of soil fertility expertise led Oxfam America to create an agricultural pilot covering 20 villages. Women and men were trained in various soil conservation measures, especially the planting of particular species of trees and bushes to help with soil fertility. A short-cycle cow pea variety was also introduced in these villages. The agricultural pilot built on the solidarity and resources of the SfC women's groups.

There is a need to further understand prior research in Mali on soil building, conservation and re-fertilization techniques, including which techniques have proved most promising. There is also interest as to how research in Mali fits with the Africa re-greening initiative. Finally, a soil baseline in the 20 pilot villages will allow us to track how soil fertility changes over subsequent years. In each of the pilot villages, women have been given a collective field on which to try agricultural techniques. Part of the plot is held as a control area with no improvements beyond what would have happened without the pilot. Pilot villages are located in the circles of Sikasso, Koutiala, Bougouni, Kati, Kolokani, Banamba and Koulikoro.

It is in this context that this study was undertaken by Oxfam America to document and summarize prior research on soil fertility and water availability in Mali, to determine the current level of soil fertility and water retention in experimental and control plots in the 20 agricultural pilot villages and to illicit farmer's knowledge on soil fertility status and water availability in agricultural production systems.

Aims of the Study and Objectives

- To discover, document and summarize prior research on soil fertility and water availability, previously undertaken by a variety of government and non-profit agencies in Mali (and West Africa) under the auspices of the Ministry of Agriculture;
    - To determine from prior studies the extent of soil fertility and agricultural water availability problems in the Koulikoro and Sikasso regions, included the estimated changes over time;

  - To identify and summarize available information about promising techniques, especially low-cost techniques, for improving organic soil fertility in Mali.

- To determine the current level of soil fertility and water retention in experimental and control plots in the 20 agricultural pilot villages;

- To illicit farmer's knowledge on soil fertility status and water availability in agricultural production systems.eu feugiat nulla facilisis at vero eros et accumsan et iusto odio dignissim qui blandit praesent luptatum zzril delenit augue duis dolore te feugait nulla facilisi.

Paper Structure

This paper has five (6) chapters. Chapter 1 presents this introduction, the aim and the objectives of the study.

Chapter 2 concerns soil fertility and water availability states in Sahelian countries of West Africa and Mali and consists of 4 subchapters. Subchapter 2.1 presents the problem of soil fertility in Sahelian countries of West Africa. In subchapter 2.2, water availabilities in Sahelian countries in West Africa are given. Subchapter 2.3 describes soil fertility state in Mali and subchapter 2.4 presents the availability of water resources in Mali.

Chapter 3 presents the study on available soil and water conservation technologies and consists of three subchapters. Subchapter 3.1 is about soil protection and water conservation techniques. In subchapter 3.2, the improvements of land use systems are presented and Subchapters 3.3 concerns adding mineral and organic fertilizers to the soil.

Chapter 4 deals with soil physico-chemical analysis, evaluation of Gliricidia sepium survival rate in the plantation in the pilot village. Chapter 4.1 presents soil physico-chemical studies and Chapter 4.2 concerns the evaluation of Gliricidia sepium trees and survival rate in the plantations.

Chapter 5 reports the base line survey carried out. Chapter 5.1 presents the introduction of farmer's knowledge on soil fertility and agricultural water availability in Koulikoro and Sikasso regions. Chapter 5.2 presents the materials and methods. Chapter 5.3 presents the results and chapter 5.4 concerns the perceptions of technical and scientist resource persons on soil fertility and water availability.

CHAPTER 2

SOIL FERTILITY AND WATER AVAILABILITY STATE IN SAHELIAN COUNTRIES OF WEST AFRICA AND MALI

Land degradation is a major constraint to the sustainability of agricultural systems in semi-arid areas of West Africa (Zougmoré et al. 2010).

Niangado (1998) reported that the soil types found in the Sahelian countries are: Luvisols, the Arenosols, Regosols, Vertisols and Nitosols. These soils have in common a broad expansion of sandy cover and a high presence of iron which is the basis for the formation of large ferruginous and gravelly soils on summits and slopes of the toposequence. The presence of armour plate and / or gravel affects the water retention capacity and soil nutrients availability. Thus, the Useful Water Reserve (UWR) was 18-32 mm/m on gravelly soils against 44-130 mm/m on other soils (Kanté, 2001). Pieri (1991) reported that because of armor plates and thin gravelly soils, 30% of the national territory of Burkina Faso is considered to have little or no agricultural value. These gravelly and unproductive soils are increasingly used in some parts of southern Mali (Kanté, 2001). Clayey soils (kaolinitic type) are found in the lower parts of the toposequence and do not allow a good storage of water and nutrients (Pieri, 1991). Breman (1998) argued that the chemical poverty and especially the extreme aridity during the dry season make the soils of Sahelian regions among the poorest of the world. Table 1 illustrates soil poverty in clay, organic matter, nutrients content, and low Cation Exchange Capacity (CEC).

Table 1 Some Physical and Chemical Soil Characteristics (0-20cm) in 2 millet production sites in West Africa.

Soil characteristics	Sadore, Niger[1]	Cinzana, Mali[2]
Soil texture (%)		
Sand	94	88
Silt	1	2
Clay	5	10
pH		
H_2O	5.3	5.9
KCl	4.3	4.9
Organic matter (%)	0.2	0.3
Total N (%)	0.01	0.04
C/N	10	4
Phosphorus		
Olsen (ppm)	4.8	11
Bray (ppm)	3.2	1.1
CEC (mq/100g)	0.96	2.9

Africa has experienced a net loss of forests exceeding 4 million ha/year between 2000 and 2005, according to the FAO (Bationo et al. 2006). This loss was mainly due to conversion of forest lands to agriculture. Forest cover went from 656 million ha to 635 million ha during this period. In the drylands of Africa, 73% of land is degraded and 51% are severely degraded (Bationo et al 2006). Loss of soil productivity due to degradation in Africa since 1950 is estimated at 20% (Dregne 1990; Bationo et al. 2006). Soil fertility depletion in the fields of smallholder farms is a fundamental biophysical root cause of the declining per capita food production, which has largely contributed to poverty and food insecurity (Bationo et al. 2006). Over 132 million tons of N, 15 million tons of P, and 90 million tons of K were lost from cropland in 37 African countries in 30 years (Smailing, 1993).

Soil organic matter is a depletable natural resource and its decline threatens soil productivity. Organic carbon concentration in the top soil is estimated at 12

1 Mean annual rainfall 560 mm on station

2 Mean annual rainfall 700 mm on station

mg/kg for humid zone, 7 mg/kg for sub-humid zone, 4 mg/kg in the semi-arid zone and 2 mg/kg for the drier semi-arid zone (Bationo et al., 2006). Most African soils are inherently very low in organic carbon (<20 to 30 mg / kg). This is due to slow root growth of crops and natural vegetation but also to the rapid turnover rates of organic matter with high soil temperature and micro fauna, especially termites (Bationo et al., 2003). There is much evidence for rapid decline of the soil organic carbon levels with continuous cultivation of crops in Africa (Bationo et al., 2003). Pieri (1989) reported that the average annual losses of organic carbon in sandy soils may be as high as 5%. According to Nandwa (2003), results from long-term soil fertility trials show that even with high levels of organic inputs, losses of up to 0.60 tons of carbon/ha/year in the soil surface layers are common in Africa.

Agro Technical Changes in Sahelian Countries of West Africa

Shifting cultivation (slash and burn) is replaced by permanent cropping in areas with heavy pressure on land. Hand cultivation is partly replaced by animal traction; this implies the expansion of cultivated areas. Indeed, between 1963 and 1990, the increase in production in sub-Saharan Africa was 47% due to the expansion of cultivated areas against 13-30% in other parts of the world. According to Kébé (1989), the increase in cultivated areas in southern Mali was about 175% between 1973 and 1989 and the increased in cotton production was 80% due to an increase of cultivated areas and 20% due to the improved productivity of the land. These changes, even though helped to increase the production, they were not accompanied by soil conservation and nutrients restoration measures. The consequences of the non-adoption of these measures are: the depletion of soil, the decrease in biomass production and soil erosion. Studies in Sudano-Sahelian Africa showed that 90% of non-irrigated lands are to varying degrees affected by desertification, i.e. degradation (Bationo et al., 1998). According to Pieri et al. (1998), around 320 million hectares have been affected to different degrees by different forms of degradation caused by human activities over the last 30 years. It is estimated that 70% of arable land and 31% of pastoral land are affected by erosion and that these lost lands were 2.5 times richer in nutrients than the remaining soil (Bationo et al. 1998).

The nutrient balances established in this area are generally negative (van der Pol, 1993). NPK deficiency is relatively lower in countries with more fallows. However, the area and age of fallows are decreasing with increasing human pressure. Under such condition, the reduction of nutrient depletion involves necessarily the local production and/or the importation of nutrients. Unfortunately the amounts of locally produced organic fertilizers are insufficient and the use of mineral fertilizers is very low. In 1993, the consumption of mineral fertilizers ranged from 6-10 kg/ha in Sahelian countries (except Niger) against 81 kg/ha in developing countries and 93 kg/ha in the rest of the world (Gerner and Harris, 1993).

Table 2: N-P-K Balance in 1983 and Fertilizers use per country

Country	Arable lands ('000 ha)	Fallows (%)	Balance (kg/ha)			*Fertilizers use (kg/ ha cultivated)	
			N	P	K	1969-71	1992-93
Burkina	6.691	50	-14	-2	-10	0.3	6
Gambie	236	29	-14	-3	-16	-	4.4
Mali	8.015	72	-8	-1	-6	2.9	10.3
Mauritanie	846	79	-7	0	-5	0.6	8.2
Niger	10.985	47	-16	-2	-11	0.1	0.4
Sénégal	5.235	53	-12	-2	-10	2	7.2

* Adapted from Kanté (2001).

A huge importation of mineral fertilizers is necessary in order to fulfill this lack of nutrients (Table 2). Knowing that such imports are unrealistic, it is essential to look for alternatives. These alternatives include: the use of locally available natural phosphates (Burkina Faso, Mali, Mauritania, Niger, Senegal); the production of organic fertilizer by composting, crop residues mulching and their use as litter in parks. In any case, the addition of organic manure is essential to maintain or increase the rate of soil organic matter and its buffering capacity.

Socio-economic changes in Sahelian countries of West Africa

The population growth rate of the world was 1.7% in the late 80s (Makken, 1993). At the same time the growth rate of the Sahelian countries was around 2.8%. Despite this growth, the region appears to be under populated and the density rarely exceeds 40 persons /km2. During the same period, the total production increased significantly in many countries. However, efforts to improve food security are inhibited by the high population growth rate. Given the population growth during these periods, output per capita fell by almost 2% per year (Pieri et al., 1998). The population growth rate, estimated at 3% per annum, exceeds the food production growth rate of only 2% per annum (Bayala, 2012). Consequently, food insecurity is growing continuously (Sanogo, 2011). The alternative solutions previously undertaken were much more focused on the extension of cultivated areas more than the increase of production.

In the context of structural adjustment imposed by IMF (International Monetary Fund) and the World Bank, subsidies for agricultural inputs was removed and this creates a serious problem for agricultural inputs acquisition by producers for the majority of which their costs are too high. Dugue (1993), found that the use of mineral fertilizer is currently marginal and less than 10 kg/ha in Yatenga (Burkina Faso) and in the Sine Saloum (Senegal). This low level is mainly due to farmer's low financial means. The devaluation of local currencies (CFA) has increased the cost of inputs importation. Traoré (1998) reported that the weak credit systems, poorly adapted to local realities also limit the investment necessary for agricultural intensification. There is a disparity in input use between areas where cereal and cash crops are cultivated. Farmers in the the later areas are generally trained by research and extension agents and have often access to inputs, equipment and credit. Thus, the cash crop areas are characterized by a rapid expansion of cultivated areas, the use of imported inputs (> 50% of the quantities imported) and a relatively improved food security (Kanté 2001).

Institutional and legislative reforms in Sahelian countries of West Africa

Legislative and institutional reforms of the agricultural sector in order to alleviate land degradation and increase crop yields are frequent in Sub- Sahelian countries. These reforms did not have enough positive impacts on farmers according to researchers (Kanté, 2001; Traoré, 1998; Sissoko, 1998). The main causes of these low impacts are summarized as follows:

- Inadequacy between the credit system and local conditions;
- Low network performance of input (fertilizers, pesticides…) supply;
- Weak systems for collecting, processing, transportation and marketing of products;
- Low level of integration of agricultural structures in decision making;
- Inefficient extension systems;
- Insufficient production and transfer of soil fertility improvement and water conservation technologies through research. These technologies should be ecologically, socio-economically and culturally adoptable.

WATER AVAILIABILITY IN SAHELIAN COUNTIES IN WEST AFRICA

Sahelian countries (Senegal, Gambia, Guinea-Bissau, Mauritania, Mali, Niger, Burkina Faso, Chad) are characterized by a tropical climate with a single rainy season lasting 2-4 months (Sissoko, 1998). Rainfall varies between 100 and 1100 mm per year. Four zones can be distinguished: the Sahelian zone (150-400 mm rainfall), the Sahelo-Sudanese (400-650 mm rainfall), the Sudano-Sahelian zone (650-900 mm rainfall) and the Sudanian zone (900 <P <1200 mm of rain). Rainfall is characterized by a high variability: total annual rainfall, starting date of the season, duration and distribution during the rainy season. Data collected between 1951 and 1960 on the annual rainfall variability in Bissau (Guinea-Bissau) and Bobo Dioulasso (Burkina Faso) show large fluctuations comparing to the mean annual rainfall (Andriesse & Windmeijer, 1993). The heavy rain drops cause erosion of fragile soils which are not protected by enough vegetation cover. The rainfall characteristics, especially during the first rains, one bare soil, reinforce the imbalances between climatic supply and water needs. These limitations place Sahelian farmers and pastoralists from the beginning to the end of the rainy season in a state of permanent drought risks (Guichard et al., 2010; Bayala, 2012). The increase in production due to the use of organic and mineral fertilizers is strongly influenced by climatic factors. In relatively arid zones, the grain yield varies from 300 to 800 kg/ha in rainy years, while it is zero in unfavorable years (Table 3).

Table 3: Annual Means of Results of Organic Matter Test in Yatenga (1984-1987).

Rainfall *RET/MET	Mean yield of the control (kg/ha)	Millet yield (kg/ ha)		
		Animal dung (powder) (5 t/ha)	Compost (5 t/ha)	Fertilizer 14-23-14 (100 kg/ha)
Unfavourable	0.3	0	Depressive	0
Mediocre	0.6	+100	+100	+150
Mean	0.75	+200	+150	+300
Favourable	0.9	+400-800	+300	+500-600

* ETR/ETM: Real Evapo-Transpiration/ Maximal Evapo-Transpiration. Millet cycle (90 days), Soil water useful reserve = 90 mm; Source: Kanté (2001).

Water erosion is a serious threat to the sustainability of agricultural land use and it affects soil productivity (Laflen and Roose 1998; Zougmoré et al. 2010). Water erosion is responsible for the negative nutrient and carbon balances in most farming systems in West Africa (Zougmoré et al. 2010) and for the reduction of crop rooting depth (Morgan, 1995). The low soil quality combined with the harsh Sahelian climate leads to a low efficiency of fertilizers (Breman et al. 2001). Erosion influences several soil properties such as top soil depth, soil organic carbon content, nutrient status, soil texture and structure, available water holding capacity and water transmission characteristics (Zougmoré et al. 2010). In addition, plant nutrient use efficiency in cereal based farming systems is often very low due to limited soil moisture (Buerkert et al. 2002). According to Lal

(1997), one of the key conditions to increase soil productivity in the sub-Saharan zone is to ensure effective water infiltration and storage in the soil.

SOIL FERTILITY STATE IN MALI

Agro Ecological Zones in Mali

Mali is a landlocked Sahelian country in West Africa situated south of Algeria, west of Burkina Faso and Niger, north of Côte d'Ivoire and Guinea, east of Mauritania and Senegal. It covers an area of 1 248 574 km^2 and has a population of 14 517 176 inhabitants, with an average growth rate of 3.6% over the period 1998-2009 (RGPH, 2009). It is divided into 8 administrative regions (Kayes, Koulikoro, Sikasso, Ségou, Mopti, Gao, Timbuktu and Kidal) and the District of Bamako. The main rivers are Senegal and Niger rivers.

There are four main agro-ecological zones in Mali (Figure 1) to which a specific area, the inland delta of the Niger River can be added.

- The south Saharan zone occupies about 50% of the territory. It is characterized by erratic rainfall <200 mm per year. Animal breeding constitutes the main activity. The millet, sorghum, wheat and rice are cultivated on the plains and near the river.

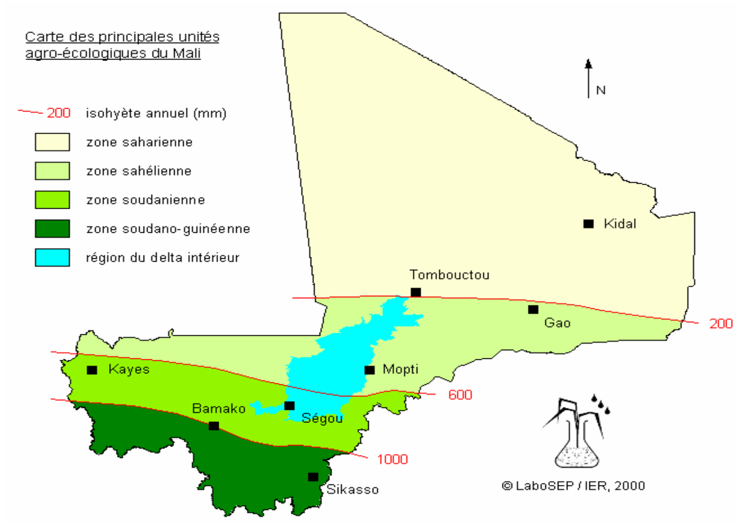
- The Sahelian zone occupies 20% (excluding the Niger Delta) territory. Rainfall varies from 200 to 700 mm per year. This is the area of millet and sorghum. The availability of many pastures promotes livestock breeding in this area.

- The North Sudanian zone occupies about 20% of the territory. Rainfall varies from 700 to 900 mm per year. Millet, sorghum, cotton, legumes, maize are grown in these areas. Live stocking is booming.

- The South Sudanian zone (Sudano- Guinean) occupies approximately 6% of the territory. Annual rainfall varies from 900 to 1200 mm and sometimes more. Cultivated crops include dry cereal, cotton, legumes, tubers and large fruit orchards are found. Relatively abundant pastures attract breeders.

- The Inner Niger Delta, located in the Sahelian zone, occupies 6% of the territory. This is the area of livestock, irrigated rice and crop diversification (gardening).

Figure 1: The Main Agro Ecological Zones in Mali



Expansion of Cultivated Areas and Land Degredation in Mali

From 19 599 700 ha of agricultural land, only 2.1 million ha are currently used around 12% (Kieft et al., 1994). The high availability of land has often resulted in subsistence farming practices and an over expansion of agricultural lands (Pieri, 1989). In Mali, the increase in production is mainly due to the expansion of cultivated areas rather than intensification. However, in the cotton and rice cropping zone, production increase is the result of a simultaneous increase of cultivated areas and crop yields. The erratic rainfall and drought risk from sowing to crop harvesting do not encourage farmers to get debt to fertilize the soil (Kanté, 2001). However, they should feed families with constantly growing size. The simplest alternative is to extend cultivated areas and manage the risk in short-term by mining the soil. Consequently, farmers in Southern Mali earn in average 30% of their income from soil nutrients depletion (van der Pol, 1993). In this region, where rainfall conditions are relatively good, the acquisition of agricultural equipment grafted to climatic uncertainties, the high costs of chemical fertilizers and the growing population needs have also encouraged the expansion of agricultural lands. This expansion is done at the expense of forest lands and fallows, thereby reduces the potential for pastures, the natural restoration of soil fertility and resistance to erosion. Unfortunately, the use of organic manure as well as mineral fertilizer is very low (Kanté, 2001). Less than 20% of cultivated areas in Mali are fertilized with mineral fertilizers. The cotton zone which receives 75% of mineral fertilizers used in Mali (Kieft et al., 1994) has only 26% of plots receiving organic manure and / or mineral fertilizer (Kanté et al., 2001). According to Pieri (1989), after 3 to 6 years of cultivation in agricultural systems with low inputs, lower yields and soil degradation were observed. Kieft et al., (1994) reported that bare soils in Mali increased from 4% to 26% between 1952 and 1975.

FAO (2000) reported that the vegetation cover in Mali decreases around 100 000 ha per year. The PIRL estimated that the rate of forest degradation was approximately 8.3% (MEATEU / DNCN, 2001). In addition to the illegal exploitation of forest resources and climatic factors, the following aspects could be highlighted:

- The surface of cleared forest lands under Forest Services authorization during the last ten years (2001-2010) is estimated at 7 743,59 ha (Camara, 2011).
- With population growth, the demand for fuel wood is very high: from 2001 to 2010 fuel wood consumption was estimated at 798 471.75 cubic meters, 5 421 919 stems for pole and 133 554 stems for timber (DNEF, 2010). Current fuelwood consumption is estimated at 1.350 kg /person/day (Camara, 2011).
- Late fires account for over 70% of burnt areas. Burned areas by late fires in 2008, 2009 and 2010 were 96 167.20 ha, 83 992.50 ha and 60 164.75 ha respectively (Camara, 2011)

Livestock Migration Southward and Mixed Farming System in Mali

Animal breeding in Mali, as in most sub-Saharan countries has experienced a series of drought periods. Many herds from the north have migrated to the south, where pastures are relatively more abundant. In southern Mali, this migration was accompanied by a partial transfer of animals from pastoralists to farmers. According Sanogo (2011) this transfer was facilitated by the availability of money from cotton and the sustained demand for oxen and livestock that may valorize the increasing amounts of agricultural by-products. Thus, in the Sikasso region, the number of cattle increased from 350 000 to 1 240 000 heads and small ruminants from 186 000 to 590 000 heads between 1965 and 1988 (Landais et al., 1991). According to recent studies, breeding is static or even declining in the North, while it continues its expansion in the South. The regression rate of animal breeding is 4% in Gao while its growth rate is 3% in Koulikoro and 3.2% in Sikasso (Landais et al., 1991). In some places in the South like Koutiala, animal stocking rate is surpassed (Brons et al., 2004; Sanogo, 2011), creating sudden problems of rangeland degradation and lack of pasture. Hiernaux et al. (1998) reported that in the Sahel, the development of livestock is a form and a means of agricultural intensification. According to Hiernaux et al. (1998), livestock is a biological agent accelerating the recycling of organic and mineral materials and their transfer within the agro-pastoral systems. In Sahelian countries, 35 to 55% of the ingested organic matter, 80 to 90% of the nitrogen and phosphorus and more than 90% of other minerals return to soil through livestock fecal and urinary excretions (Hiernaux et al., 1998).

Socio-economic Situation in Mali

The rural sector occupies a prominent place in the Malian economy. Agriculture and livestock contribute about 23% of exportation and 40% of gross domestic product (Dicko et al., 2006; Sanogo, 2011). Mali has undertaken economic reforms called structural adjustment in 1980 with the support of the World Bank, the International Monetary Fund and other development partners. The implemented programs have affected many sectors of the economy, particularly the agricultural sector with Adjustment Programs of Agricultural Sector (PASA). These policies included specific reforms aimed to influence the profitability of farms with better prices to producers. It is in this context that Cereal Market Restructuring Program (PRMC) was initiated in the early 1980s. Before this, the State had the monopoly of marketing through the Malian Office of Agricultural Products (OPAM). In addition, Mali has undertaken in 2006, with technical and financial support of UNDP in the elaboration of a ten-year plan (2006-2015) for the achievement of the Millennium Development Goals (MDGs).

Currently, the socio-economic situation is characterized by the implementation of the second generation CSLP denominated Strategic Framework for Growth and Poverty Reduction (CSCRP) 2007-2011 adopted by the government on 20 December 2006 after the consultation of all development partners and the preparation of the third generation which covers 2012-2017 period. In Mali, with the targeted growth rate of 7%, CSCRP is the unifying framework of all components of national development. Unlike the other two generations, the third one put particular attention to the protection of the environment (Camara, 2011).

Agricultural imports constitute 50 to 55% (about 40% of equipment and inputs) of all imports. In addition to equipment and inputs, Mali imports cereals. However, it is self-sufficient and exporter in years of good rainfall.
In Mali, the input prices are growing faster than that of products. The devaluation of local currency occurred in 1994 doubled the price of inputs.

Market integration improves the living standard of farmers in favorable conditions but it also creates new needs which weaken the rural areas. There is a more pronounced differentiation of farms, the splitting of large farms, which lead to land fragmentation, cropping of marginal lands and the difficulties in common properties management (Kanté 2001).

During the 8-10 months of the dry season, many rural young people are moving to towns in search of money. According to Delville (1996) migration in the Sahel affects 25-30% of active men but Amoukou et al. (1996) reported that it could reach even 70-80%. This variation observed by the authors is based on socio-economic realities of the communities studied. Young people seek income outside the agricultural sector and are no longer available for the work required for maintaining rural society (van der Pol & Giraudy, 1993). Many families are experiencing labor crises in the dry season for the production of organic manure.

However, the process of soil fertility restoration involves necessarily the control of soil erosion and the maintenance of organic matter in the soil (Kanté, 2001).

Strategies for Soil Fertility Management in Mali from 1960 to 2013

In order to improve and maintain soil fertility, many strategies have been developed and implemented in Mali from 1960 to 2013. Fertilization strategies implemented included sectoral approaches (CMDT or Groundnut Operation) and national initiatives (Soil Fertility Initiative and Rice Initiative). These major strategies include:

1. The sectoral approach;
2. The national plan for integrated soil fertility management;
3. Sustainable land management (SLM);
4. The microdose of fertilizers;
5. The rice initiative;
6. The soil fertility map of Mali.

The Sectoral Approach

The sectoral approach of soil fertility management was adopted in 1960 by the Government of the Republic of Mali (GRM). The aim of this approach was to create companies, operations or agricultural development offices such as CMDT, Operation Peanut, Operation Food Crops, Mopti Operation Millet, Niger Office, Mopti Rice Office etc.

A fertilization formula was developed for each crop. Thus, 100 kg / ha of DAP, 50 kg of urea and 5000 kg per ha of organic manure or compost are recommended for sorghum (Pieri, 1973; Poulain, 1976). These formulas tended to correct only the deficiencies of the main nutrients (Pieri, 1973). Extension services of the various offices, operations or companies had then the task to reinforce the adoption of these fertilization formulas by farmers. Socio-economic and agro-ecological conditions influenced the applications of formulas by farmers and research results users. Mali then used 175,000 tons of fertilizer for an average of 8 kg ha-1 of cropland (Kelly et al. 1998). However, this fertilization strategy by sector had negative impacts such as: an over use of mineral fertilizers on irrigated rice; an inefficient use of mineral fertilizers on cotton; a very low fertilizer use on dry cereal, an insufficient use of organic manure; a growing collection of crop residues and soil mining.

The National Plan for Integrated Soil Fertility Management (ISFM)

Fertilization strategy or management of soil fertility through sectoral approach has resulted in the degradation of natural resources, including a general decline in soil fertility, hence the need for an initiative to restore the Soil Fertility (IFS) in Mali, as in many other countries in West Africa (MDR, 2002) was necessary. This initiative has resulted in Plan called ISFM. This National Plan or Action Plan consisted of interventions of soil fertility management at country and specifically at regional levels (MDR, 2002). In the context of ISFM, concrete actions to be applied are:

- The use of production factors, including organic and inorganic fertilizers, taking into account the low financial means of farmers. The restitution of organic manure is not a choice compared to the use of mineral fertilizers but an obligation which determines the maintenance of soil fertility and fertilizer efficiency at the long run.
- Extension activities should be strengthened and the research efforts should focus on the valorization of local minerals (phosphate and calcium - magnesium complex);
- The development and management of forest resources (assisted regeneration, enrichment and valorization). In agroforestry, it is in the fields that activities should be done by the farmers themselves, given the fact that they are owner of planted trees;
- The application of soil and water conservation methods.

Since its adoption by the Government of Mali, the action plan ISFM did not get the necessary funds for the implementation of specific actions at regional levels. This plan instead became a strategic framework that continues to mark the sectoral approach. This plan also became the frame of many other strategies such as:

- The Agricultural Orientation Law (LOA) which is a agricultural policy aiming to create better conditions of farmers access to fertilizers and fertilization strategies;
- The SLM (Sustainable Land Management) includes a more environmental option for fertilization and other ISFM practices.

The Microdose Fertilizer

According to Kelly et al. (1998) the bad agro-socio-economic conditions did not encourage the use of chemical fertilizers on dry cereal, including sorghum and millets; this led to the development of lower but effective doses of fertilizer called microdoses (ICRISAT, 2004; Aune et al. 2007). They are suitable for sorghum and millet that do not valorize fertilizers economically. The microdose fertilizer targets small farmers for the applications of 0.3 to 2 g of fertilizer placed in the same planting hole as the seed (Aune et al. 2007). The efficiency of the fertilizer is then about 25 kg of millet per kg of fertilizer (against 1.7 for the classical fertilization of 150 kg ha-1). This strategy of crop fertilization was introduced into the areas of Bafoulabé, Macina, Bankass and Koro in 2000 (Aune et al. 2007). It has been used in the regions of Ségou, Koulikoro and Mopti in 2002 (ICRISAT, 2004). Then the microdose project of the Alliance for a Green Revolution in Africa (AGRA) was launched in Mali in 2009. This strategy of microdose fertilization is also mechanized (and widely used) for simultaneous placement of fertilizer and seed (Coulibaly et al. 2010).

However, the technique of microdose is currently subject to debate in the context of sustainable land management.

Sustainable Land Management

The non-implementation of the National Plan ISFM has accentuated soil and water degradation. Thus, because of the loss of soil fertility due to poor farming practices (Doumbia et al., 2007); farmers are forced to cultivate new fragile lands with shallow soil (the so-called marginal lands). Cultivated areas are increasing at a rate of 4.7% per year. The economic impact of land degradation is enormous. In the Sudanian zone, for example, the loss of farm income is estimated at 90 000 F CFA per hectare per year (Doumbia et al. 2007). Faced with these constraints, the Government of Mali has decided to be heavily involved in a process called SLM in February 2007 in partnership with TerrAfrica. A Strategic Investment Framework for SLM was adopted to perform priority actions, including those related to ISFM (Doumbia et al., 2007):

- bio drainage of Niger Office soil using a rapid bio drainer such as Eucalyptus species that rapidly eliminates the groundwater by transpiration into the atmosphere (Rajamani, 2005). The canopy of a eucalyptus tree can reduce the level of groundwater from 1 to 2 m depth in 3 to 5 years (Heuperman and Kapoor, 2002).
- CLM (Contour line management) and specific formulas of fertilization: Integrated management of rainwater to specific fertilization formulas (regional formulas, formulas adapted to soil properties and formulas based on yield performance).
- Agroforestry: Promotion of hedges around fields using Jatropha curcas.
- Enrichment of pastures: specifically the enrichment of grazing land with Acacia albida, Acacia senegal or perennial herbaceous plants.

Sustainable Land Management strategy is implemented very cautiously, and the specific activities described above are expected to be applied at farm level at large-scale.

The Rice Initiative

The main objective of the Rice Initiative is to increase agricultural production by reducing production costs, especially those of the inputs. As part of this Initiative Rice, the Government of Mali is committed to provide subsidy to fertilizers, seeds, equipment and advisory support. This initiative, which covered only rice in 2008 (CPM, 2008), was gradually extended to cover other crops such as maize, wheat, sorghum, millet and cotton (MA, 2012). One of the major impacts of this soil fertility management strategy was that the use of fertilizer in Mali reach 48 kg/ha, which is about the goals of the Abuja Declaration (2006). This declaration stated that the amount of fertilizer use should reach 50 kg/ha by 2015; the total cultivated area is estimated at 7.4 million ha (MA, 2012). The Initiative has helped to bring the fertilizer use from 175 000 tons in 1998 to 337 030 tons in 2012.

Soil Fertility Map

The development of a Soil Fertility Map of Mali was initiated in 2011 between the Government of Mali, the Phosphate Office (OCP) of Morocco, the Agricultural Research Institute of Morocco (ARIM) and Toguna Agribusiness Company in Mali. This map is believed to be a geographic and scientific database of soil resources in Mali. Based on a better knowledge of soils, the fertility map should increase productivity by an appropriate use of mineral and organic fertilizers. This map meets the needs of users who require more specific recommendations (MDR, 2002). These specific recommendations include regional fertilization (regions CMDT), or based on yield performance objectives or based on soil properties. For the first phase of the pilot project two strategic areas of the National Action Plan for the Integrated Management of Soil Fertility (MDR, 2002) are chosen:

- The area of Niger Office for rice and tomato production;
- The CMDT area for cotton, corn, sorghum and millet.

The Laboratory Soil-Water and Plant (IER) is leader of this project that involves all stakeholders, including the IPR / IFRA of Katibougou for training aspects and the Agriculture National Direction for the communication and extension of results.

AVAILABILITY OF WATER RESOURCES IN MALI

Concerning the management of water resources, the actual reference is the law n ° 02-006 of 31 January 2002 on the Water Code. This Act establishes the implementation of the blueprint for Water Resources Planning which represents a management plan projected for a period of twenty years. All the local stakeholders, organized in basins or sub-basins committees must refer to this blueprint as a working tool. Then, management by watershed or aquifer system is the basis for the integrated management of water resources in Mali.

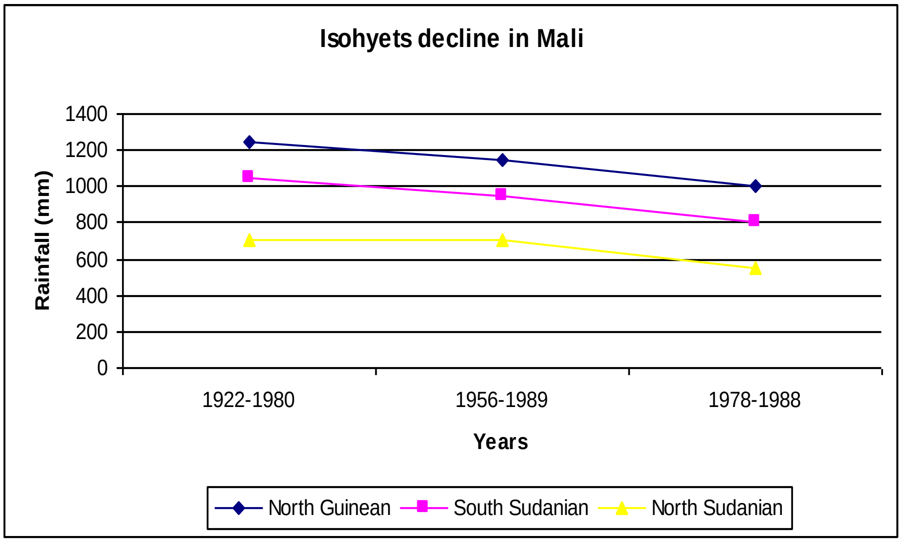
Rainwater in Mali

Rainwater constitutes the main water resources of Mali and provides in average 415 billion m^3 of water per year.

According to the aridity index described by UNESCO (1977), more than 90% of the area of Mali are considered arid and more specifically 47% of lands in Mali are hyper arid. This drought becomes more pronounced due to the reduction of the mean annual rainfall. A comparison between the years 1950s and 2000s reveals downward trend of isohyets from North to South (NAPA, 2005). In addition, isohyet with a mean annual rainfall of 1400 mm is no longer present in Mali.

According to Bitchibaly & Dioni (1992), the rainfall of the last 10 years is on average 200-250 mm lower than that obtained 60 years ago (Figure 2). This decrease of rainfall called isohyets decline by Delville (1996) resulted in a decrease in biomass production, forcing farmers to expand cultivated areas at the expense of fallows in order to meet the needs of the growing population.

Figure 2: Isohyets declinde adaped from Bitchibaly and Dioni, 1992 (South Mali)



The tendency curve from figures 3, 4 and 6 represent the rainfall trend in Kolokani, Bougouni and Koutiala respectively and indicates a decrease in rainfall in these areas from years 90s to 2000s. The decreasing trend in rainfall is not clear in the case of Sikasso during the 17 years of observation (Fig. 5). However in Sotuba (Fig.7) the trend is the increase in rainfall during the 22 years of observation. The rainfall data presented here are those available at the Agro-meteorological research Unit at IER Research Centre of Sotuba.

Figure 3: Rainfall in Kolokani from 1990 to 2004

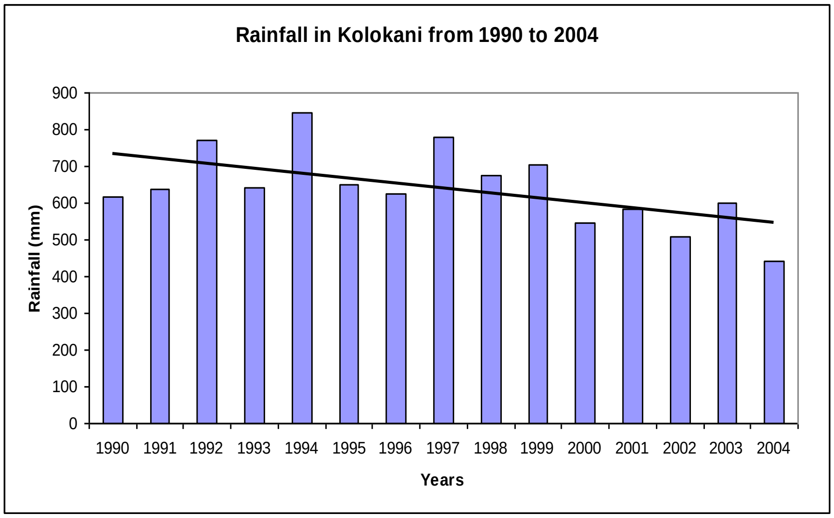


Figure 4: Rainfall in Bougouni from 1990 to 2007

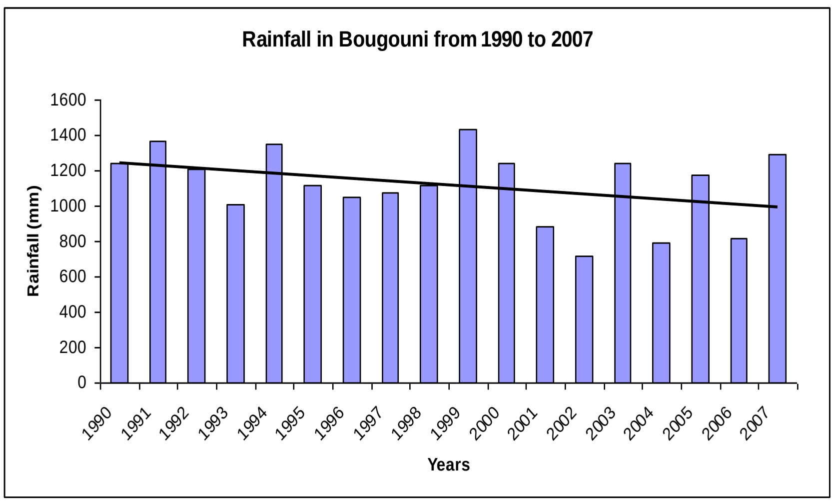


Figure 5: Rainfall in Sikasso from 1994 to 2010

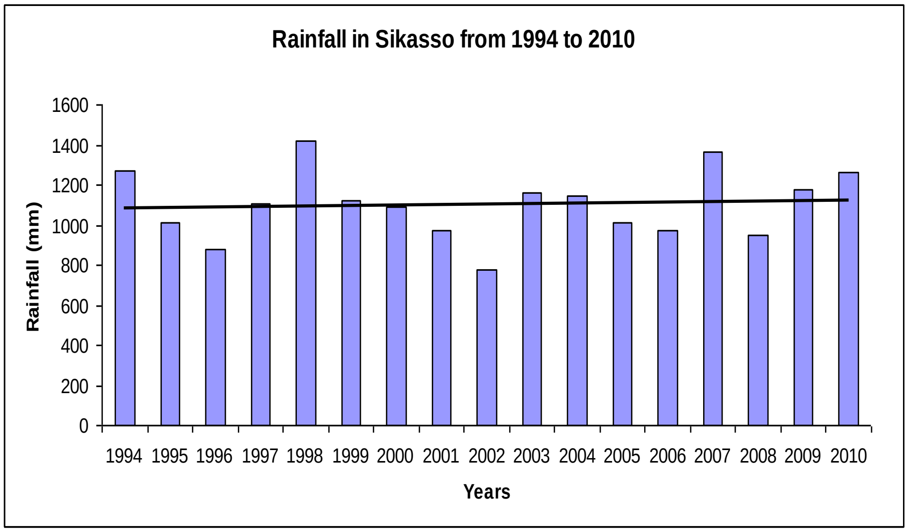


Figure 6: Rainfall in Koutiala from 1990 to 2008

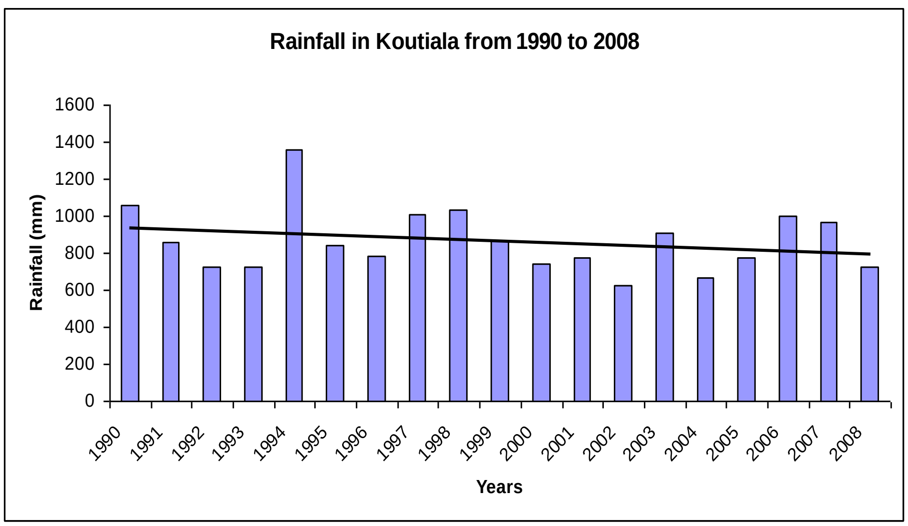
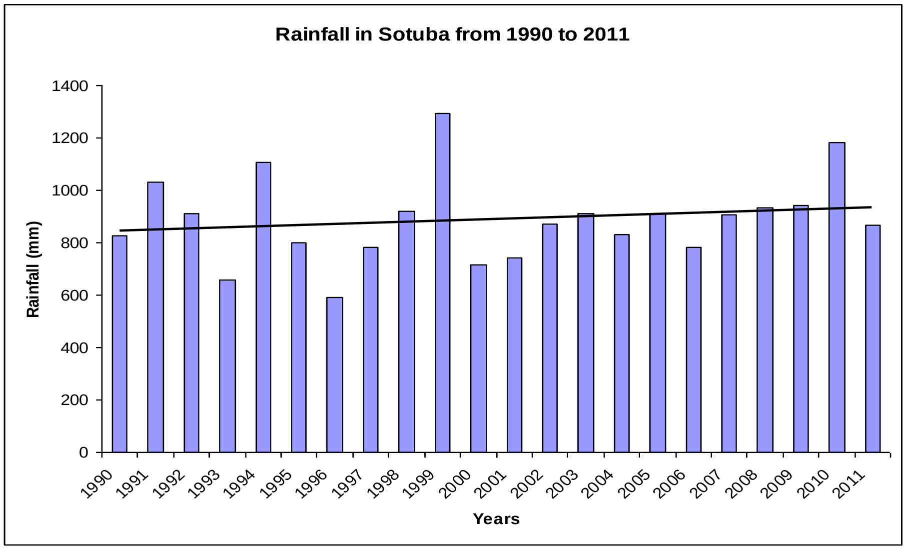


Figure 7: Rainfall in Soutuba (Koulikoro) from 1990 to 2011



Watersheds (Perennial Surface Water) in Mali

The hydrographic system of Mali is mainly composed of three basins: The Niger, Senegal and Volta basins (Table 4). Six sub-basins are attached to these three major rivers forming the perennial rivers in Mali. The perennial rivers are located in the south and center of the country while the north numerous fossil valleys are present.

The Niger and Senegal rivers have a potential annual flow of 46 billion m^3 and 14.5 billion m^3 of water in Koulikoro and Kayes respectively. These two rivers drain an average of 70 billion m^3 of water (110 billion m^3 of water in wet years and 30 billion m^3 in a dry year).

Table 4: Major river basins and sub basins in Mali

Sub-basin or secondary rivers	Basin or Main River	Watershed Surface (Km^2)	River Length (Km)
Bani Sankarani	Niger	570,000	1,740
Baoulé Bafing Bakoye	Sénégal	155,00	800
Sourou	Volta	14,500	80

Non Permanent Surface Waters in Mali

They are estimated at about 15 billion m^3, and contribute to the water supply of population and especially cattle.

The Groundwater Resources

Aquifers of Mali are classified into three categories according to the mode of occurrence of groundwater: generalized aquifer, superficial aquifers and fractured aquifers. They are estimated at 2 700 billion m^3 with a turnover estimated at 66 billion m^3. It should be noted that existing resources are characterized by seasonal variability related to rainfall and low groundwater recharge capacity (MEME, 2007).
Table 5 shows that the mean renewable resources are of 71 billion m^3 for surface water and 66 billion m^3 of groundwater, then a total of 137 billion m3.

Table 5: Rainfall and Renewable Water Resources in Mali

Rainfall and Renewable water resources in Mali	Volume (billion m^3)
Rainfall	415
Permanent surface water	56
Non permanent surfaces water	15
Renewable groundwater	66
Total renewable water	**137**

National report on the development of water resources, GNH, 2006

Quality of Water Reources

Despite the continuing deterioration of the quality of surface water, the results of punctual measurements do not show the presence of an alarming physical or chemical pollution. But a poor bacteriological quality (total and fecal coliform > 5000 colonies per 100 ml) was observed and therefore the water is not suitable for consumption without prior treatment (MEME, 2007). Despite their purifying power (MEME 2007), the main rivers and their tributaries, are increasingly subjected to various sources of pressure:

- Human and animal organic waste (domestic wastewater);
- Organic and chemical fertilizers and pesticides;
- Discharges or uncontrolled industrial effluents in urban centers.

Current Use of Water Resources in Mali

According to Diarra (2006) the current use of water resources for different sectors of the economy are summarized in Table 6. The data presented on livestock have been reported by Livestock National Policy Document (2003), those for the energy from Water National Policy Document and those on industry from the National Report on the Development of Water Resources.

Table 6: Actual Use of Water in Mali

Uages	Exploited volume in m^3	%
Drinking water supply in rural and semi urban areas	46	.22
Drinking water supply in urban areas	61	.29
Irrigation	5000	23.53
Livestock	75	.35
Energy	16067	75.60
Industry	4	.01
Total	**21253**	**100**

Adequacy Requirements/ Resource in Mali

Annual water needs in Mali are estimated at about 19.7 billion m3 including water for hydroelectricity, which represents 81% of the needs. The water needs of Mali are estimated at about 14% of renewable water resources. Water consumption without energy use is only 2.5% of renewable resources. Consequently, it is obvious that Mali has a large water potential. This potential, if properly managed with adequate technologies will meet the long-term needs of drinking water supply, irrigation and hydropower needs of the country (MEME, 2007).

At the international level, the threshold of water scarcity is 1000 m^3 per person/year. An assessment done by the United Nations in 1998 showed that the internal renewable water (average annual flow generated from endogenous precipitation) in Mali amounted to 5071 m^3/person/year and the global renewable water resources (internal resource + flows generated outside the country, flows out of the country) are estimated at 8452m^3/person/year. According MEME (2007), the country is well above the threshold of shortage concerning the availability of water resources.

Water shortage is therefore more a financial and/or technical problem rather than a lack of resources. However, the disparities of water resources across the country exist, especially for some Sahelian and Saharan zones.

Water Needs for Irrigated Agriculture in Mali by 2025

Agricultural water needs are estimated at 12 billion m^3 or about 30% of surface water resources in the river in years of rainfall deficit. Table 7 presents the irrigation potential of the Niger River Basin and its tributaries from 2005 to 2025.

Table 7: Evaluation of Withdrawals and Water needs of the Niger Basin in Mali

	Superficie (ha)			Volume Mm^3		
	2005	**2015**	**2025**	**2005**	**2015**	**2025**
Total Contol	117,348	232,223	450,223	3,824	6,107	10,740
Controlled	167,846	216,796	307,796	-	558	1,168
Natural	60,000	60,000	60,000	-	-	-
Total	**21253**				**100**	

Problems of Degradation of Water Resources in Mali

The main degradations of water resources are: domestic pollution, degradation and illegal occupation of banks, industrial and traditional pollution, deforestation, the silting of rivers and pollution related to agricultural activities.

- **Domestic Pollution**

These pollutants are mainly from industrial, traditional and domestic. Networks of wastewater canals and sewer systems are old and often insufficient for channeling increasing volumes of wastewater discharged by cities. These untreated waters (for domestic, industrial, hospital) are discharged directly into the environment, polluting surface water and groundwater creating sometimes serious health problems.

- **Degradation and Illegal Occupation of River Banks**

The illegal occupation of the banks for agricultural purposes, such as urbanization or garbage dumps has promoted erosion. The collapse of banks lead to the expansion of river beds and constitutes a serious threat to the survival of many communities. Gardening activities in the rivers involve the use of huge amounts of fertilizer that always end up in the river or groundwater. For example, in Bamako, MEME (2007) identified 1000 gardeners using nearly 200 tons of fertilizer per year.

- **Industrial and Traditional Pollution**

The industries located along the Niger collect large quantities of water and reject most of it after use. According Tecsult (2001), the flow of the discharge is estimated at 3 000 m^3/day. The Niger River receives annually more than 800 000 m^3 of wastewater from large industrial units as well as small traditional dyers (MEME, 2007).

- **Deforestation and Silting**

The reduction of water resources potential caused by adverse weather conditions has been exacerbated by human activities that have helped to destroy the vegetation and soils.

The consequences of vegetation destruction by man is huge, the rate of soil erosion that is the result varies from 10 to 25 tons per km^2 per year. The rate of deforestation in turn is around 100 000 ha / year. Human induced bare soils are directly exposed to wind and water erosion. We are thus assisting to the silting of rivers, ponds and lakes, to the regression of savannah in favor of the Sahel and the decline of the latter due to flow of sand from the desert (desertification). All this leads to a lowering of the water table and the reducing of rainfall frequency. The silting phenomenon, common to all rivers in Mali, causes an annual deposit of nearly 13 million tons of silt in the beds of the main rivers (MEME, 2007). It is important to mention that the exploitation of sand in rivers is contributing significantly to resource degradation due to the mismanagement of this activity.

- **Pollution relted to Agricultural Activities**

Chemical inputs (phosphate and nitrate) and pesticides are leached by seepage into the shallow aquifers causing in the long run a marked pollution of groundwater. According to Diarra (2006), the Niger Office in 1994 consumed 939 tons of urea and 4055 tons of ammonium phosphate on 47 000 ha of irrigated lands, but also a large amount of zinc sulfate to treat deficiency problems.

CHAPTER 3

AVAILABLE SOIL AND WATER CONSERVATION TECHNOLOGIES

Nutrient management technologies at farm level have essentially three goals: 1) adding 2) recycling and 3) protecting. According to Bationo et al. (1996), these different technologies can be grouped into techniques such as:

1. Soil protection and water conservation;
2. Improvement of land use systems;
3. Adding mineral and organic fertilizers.

Soil Protection and Water Conservation

Available technologies and measures to protect soil and conserve water are numerous. Among them we can find:

Stone Rows

Arranged along the contour lines, stones bunds are generally used in the upslope parts of the toposequence where armor blocks and pebbles are abundant. Stones lines have in 3 years of use allowed a vegetation cover about 100% of bare plots (Gakou et al. 1996). They allow a reduction of the impact of erosion.

Mulching

Covering the soil with crop residues (mulch or straw mulch) reduces the impact of rainwater on the ground and protects it against sunlight. Mulching reduces water erosion, runoff, soil temperature and soil water evaporation. However, for many farmers, the recommended amount of biomass needed for good protection (8 t ha^{-1}) is too high (Gakou et al. 1996). However, an amount of 1 to 1.5 t ha^{-1} of straw can reduce soil particles transport by wind from 42 to 63% (Sterk & Stroosnijder, 1998).

Tests were conducted in Burkina Faso Agricultural Research Center Saria to evaluate the effect of mulching using leaves and stems of trees and shrubs, to reduce soil erosion and improve soil fertility and crop yields. The treatments used were as follows: control, leaves of *Azadirachta indica*, *A. indica* leaves plus aerobic compost of sorghum straw, aerobic compost, *Acacia holocericea* phyllodes and wild grass. The mulching rate was 5 t ha^{-1} of dry matter and base mineral fertilizer was applied to all plots. The results showed that *Azadirachta indica* leaves, *A. indica* leaves plus compost, wild grass and *Acacia holocericea* phyllodes treatments significantly influence the soil by conserving water reducing temperature compared with the control or the treatment with compost alone. Plots treated with *Azadirachta indica* leaves, *A. indica* leaves plus compost or compost alone gave the highest grain yield (1.54 times greater than the control), which corresponds to a grain yield increase of 554 kg ha^{-1} when averaged over the three years of study. The highest yields were obtained with mulch that combines high nutrients delivery with water conservation and temperature reduction namely leaves of *A. indica* (Tilander and Bonzi, 1997). However Tilander and Bonzi (1997) gave no information on the land area needed to produce 5 tons of mulch they have tested (Bayala, 2011). Bationo et al. (2004) reported that the use of *A. indica* leaves as mulch is widespread in an area of 3 km around the homestead in many villages of Bulkiemdé Province on the Central Plateau of Burkina Faso but they failed to provide information on the quantities of leave produced and their effect on soils.

Ridging (Ploughing)

Embankments of soil are made at various intervals between ridges or mounds (Gakou et al. 1996). It allows the conservation of water in micro-catchment's basins and reduces erosion (Perrier, 1987). Thus, according to Kanté (2001), partitioning of ridges can increase the infiltration from 10 to 20 mm of water per rain. Partitioning has increased cotton yield by 6.3% (Poel & Kaya, 1988). The best effects on sorghum yields were obtained with micro-basins of 0.5 m^2 and 1 m^2 for millet (Perrier, 1987). But partitioning of heavy soils can cause a negative effect on yields, resulting in the asphyxiation of roots when it is too wet.
From a study performed at Cinzana research station, Kouyaté and Wendt (1991) showed that the water balance, estimated from measurements done with neutron probe, indicated an increase in sorghum water use efficiency due to ridging to 4% in 1986 (wet year) and 203% in 1987 (relatively dry year).

Zaï

The zaï technique is widespread in Dogon Plateau and is well adapted to the Sudano- sahelian zone (Bengaly, 2008; Bayala, 2011). Zaï is a technique for recovering encrusted soils that consist of digging holes of 20 to 40 cm in diameter and 10 to 15 cm deep to collect surface water and increase infiltration. It is traditionally used in Yatenga (Burkina Faso) and even in Niger. These holes are enriched with manure or compost. According to Gakou et al. (1996), the number of farmers who adopted the technique in Tominian area was multiplied by 14 in 1993. Zaï is quite efficient in recovering degraded lands (Kanté, 2001). The project implemented by the Djénné Agricultural System (SAD) in 1989-1990 showed that agricultural production can be increased up to 1000 kg ha^{-1}

compared with traditional ploughed control plots. About 1600 farmers from 17 villages have adopted the technology through this project (Bayala, 2011). The effect of zaï on sorghum yield was evaluated by Reij et al. (1996). The results indicate that the use of zai alone has a small increase on sorghum yields (only 200kg ha^{-1}). However, high yields are obtained (1700 kg ha^{-1}) when the technique is combined with organic manure and fertilizer. The adoption of the technique does not require sophisticated equipment or special knowledge.

Half-moons

Half-moons are half-circle shape water harvesting structures dug perpendicular to the slope and surrounded by downstream or so-called earth glasses, prolonged by wings of stone or earth. Half-moons are used to collect surface water, stabilize soils on steep slopes and recover degraded soils. However, the constraints of half-moons are numerous: (i) the difficulty of mechanizing agricultural work, (ii) the need for maintenance, (iii) the ability to plant only 20% of the plot area, and iv) the economic profitability is not obvious (cost equal 3 times that the stone bunds and 2 times that of the zaï).

The Countour Line Management Techinque

The technique involves making bunds (teens) following the contour lines. The distance between the curves is determined according to the slope of the land. Bands between the bunds are plowed parallel to bunds. This technique reduces runoff and promotes infiltration of rainwater. It was recorded in a farmer field in Konobougou (Fana CMDT region) an increase of cotton yields from 600 kg ha^{-1} in 1993 to 850 in 1994 and 1000 in 1995 (Gigou & Traoré, 1995).

Gigou et al. (2006) have described a type of contour line management done in an individual field. The aim was to reduce the runoff of rainwater in order to increase immediate returns. These results could be applied to the cotton region of Mali, Burkina Faso and northern Côte d'Ivoire, where animal traction is practiced. The results showed that the additional infiltration is about 10% of the total rainfall and the yield increase is about 30% in dry years. The yield variations are also reduced. Table 8 shows the decrease of runoff due to contour line management (slope 1-2%). Cereal yields increase due to contour line management is presented in Table 9.

Table 8 Reduced Runoff due to Contour Line Management (Gigou et al. 2006)

Year	1995		1996		2002	
Countour Lines	With	Without	With	Without	With	Without
Rainfall	630 mm		633 mm		663 mm	
High Slope	21% D= 64 mm	31%	40% D= 97 mm	55%	26% D= 48 mm	33%
Down Slope	14% D = 72 mm	25%	40% D = 42 mm	47%	20% D = 45 mm	26%

D= mm of water retained by contour lines; %: part of rainfall lost through runoff.

Table 9 Cereal yeilds Increase due to Contour Line Management (grain in kg/ha)

	Maize			Millet		
Year	**1998**	**1999**	**2000**	**1998**	**1999**	**2000**
Number of Trials	2	10	6	3	5	7
Without Contour Lines	2603	2082[a]	1550[a]	892	1430	630[a]
With Contour Lines	3599	2836[b]	2088[b]	1128	1453	1008[b]
%Yield Increase	38	36	35	27	2	60

a, b: values in the same columns fllowed by different letters are significantly different at P= 0.05

According to Gigou et al. (2006), contour line management technique represents for farmers a simple, easily appropriable and highly profitable technology. Most of the experiments reported above were performed Konobougou. Thus, in the neighboring villages, around 108 farms have requested contour line management. Faced with this demand, the supply of services is insufficient because the installation of the technique requires simple topography equipments. One of the main limitations of this technique is the frequent breaking of teens during the first years before vegetation stabilization.

Improving the Land Use System

Hedges

Several species of shrubs can be used to delineate or protect the fields. Among them, we can note the *Euphorbia balsamifera*, *Jatropha curcas* (jatropha), *Citrus limon* (lemon), *Cajanus cajan* (pigeon pea), *Leucaena leucocephala* , *Agave sisalana* (Sisal) and *Ziziphus mauritania*, etc. The use of multipurpose hedgerows should be encouraged. Thus, while some species such as *Euphorbia balsamifera* have limited utility for the sole protection of the soil, others like pigeon pea, in addition to their positive influence on the ground are animal's fodder. Hedgerows, depending on the species enhance biological fixation of nitrogen, mycorhization and nutrients uptake from subsoil by perennials. Hedgerows reduce erosion and leaching beyond the rooting zone (Kanté, 2001).

Grass Strips

Grass strips in the fields reduce runoff and promote infiltration of rainwater. Farmers usually establish grass strips of 3 m width with a spacing of 50 m between strips. With regard to species tested as *Vigna unguiculata* (cowpea), *Digitaria exilis* (fonio), *Brachiaria ruziziensis*, *Stylosanthes hamata*, *Andropogon gayanus*, the associations such as *Brachiaria ruziziensis* and *Stylosanthes hamata*) are more viable in time compared to each species taken separately (Gakou et al., 1996; Hijkoop et al. 1991). *Andropogon gayanus*, although difficult to establish has a long life and can withstand fire and grazing, and is therefore the preferred species. In new clearing areas, the band may consist of natural vegetation, resulting in an improved clearing.

A combination of technique with stone bunds and grass strips with or without fertilizer and compost was tested in a research station in Burkina Faso. The runoff was reduced by 53% with stone bunds and 45% with grass strips. The erosion-control devices in combination with compost improve sorghum yields to 106% and 160% respectively (Zougmoré et al., 2003).

Forage Sole or Improved Fallows

The introduction of a legume sole or an improved fallow in the rotation helps shorten the duration of the fallow and ensures better tree- crop-livestock integration. Protecting the sole and seed production are the main constraints. According to Bosma et al. (1999), the balance of organic matter can be positive with a rotation including about 17% of improved fallow, accompanied by efficient recycling of crop residues. In addition herbaceous species such as *Stylosanthes hamata* and some tree species such as *Acacia auriculiformis* are used for improved fallows. According to a study performed in Korhogo (north of Côte d'Ivoire), Louppe et al. (1998) reported an enrichment of nitrogen of 400 kg / ha

under *Acacia auriculiformis* compared to *Eucalyptus camaldulensis*, and 150 kg / ha compared to *Gmelina arborea*. According to Louppe et al. (1998), *Acacia auriculiformis* in Korhogo nodulate well in nurseries with local strains of Rhizobium and 96% of nodules are efficient.
Gliricidia sepium - *Stylosanthes hamata* association gives good results. The amounts of carbon and nitrogen are respectively 970 and 60 kg ha^{-1} for the association against 430 and 30 kg ha^{-1} for *Gliricidia sepium* alone (Yossi et al. 2000). The residual effect of *Stylosanthes hamata* on sorghum yield in the consecutive three years following the forage sole is estimated at 450, 200 and 50 kg ha^{-1} (Hoefsloot et al., 1993). In addition to the positive effect on soil fertility, the quality of fodder produced is improved.

Yossi et al (2002) conducted at IPR-IFRA's research station in Katibougou (Koulikoro region) a study on the influence of *Mucuna cochincinensis* fallow and the incorporation of biomass with or without NPT (Natural rock phosphate of Tilemnsi) on fertility and millet yield. They observed an increase in nitrogen and soil pH regardless of the management option. Simple effect of fallow type and biomass management factors had a significant impact on the performance of millet. The highest yields were obtained after a Mucuna fallow (2.81 t ha^{-1}) and the incorporation of biomass (2.85 t ha^{-1}). The superiority of the performance after the incorporation of the biomass can be explained by the stimulation of soil microbial activity due to the buried fresh organic matter.

In another experiment, four treatments were used: sorghum plus NPT, sorghum associated with *Stylosanthes hamata* incorporated plus NPT, sorghum associated with *Stylosanthes hamata* without biomass incorporation plus NPT and sorghum without NPT. These treatments produced a biomass of 9.35 t ha^{-1}, 11.18 t ha^{-1}, 8.37 t ha^{-1} and 7.48 t ha^{-1} respectively. The highest yield was obtained with sorghum associated with *S. hamata* incorporated biomass (1.91 t ha-1) and lowest yields in pure sorghum plots without NPT.

Based on a survey conducted at Katibougou (Koulikoro), Samaya and Samanko (Bamako) *Guiera senegalensis* and *Combretum lecardii* were identified as species with high potential for their use as green manure. On the basis of this survey, Tangara (1996) evaluated the effect of the application of their biomass on sorghum yields at the research station at ICRISAT Samanko compared with farmer's practice. The results revealed a significant difference between treatments for only the dry biomass with *C. lecardii* (2.5 t ha^{-1} yr^{-1}) and *G. senegalensis* (5 t ha^{-1} yr^{-1}) giving the highest yields. Soil analysis carried out after 4 years showed that the applied biomass was not yet fully mineralized to have any impact on soil properties.

A series of tests on improved fallows were conducted at the Institute of Rural Economy using trees, the majority being nitrogen fixing trees (Yossi et al 2002). Survival rates were higher for species such as *Acacia senegal*, *Sclerocarya* *birrea* and *Acacia raddiana* whereas the highest growth was obtained with *Acacia seyal*, *A. raddiana* and *A. senegal*. Improved fallows of *Acacia auriculiformis*, *Acacia mangium*, *A. senegal*, *Albizia lebbek*, *Gliricida sepium*, *Pterocarpus erinaceus* and natural fallow were evaluated at the research station of Sotuba for the number of spores of mycorrhizal fungi. Exception for the fallow of *A. lebbek*, soils of other improved fallows contain more spores than the natural fallow. Mycorrhizal activity was more intense in the soil of *A. auriculiformis*. Thus, five species (*A. auriculiformis*, *A. mangium*, *G. sepium, A. lebbek* and *Prosopis africana*) improved soil porosity which is an important physical characteristic of the soil: the improvement was due to their root systems, their litter decomposition into the soil and their mycorrhizal and symbiotic associations. The organic matter content was higher in *Acacia mangium* fallow (1.4%) followed by that of *Gliricida sepium* (1.1%). While tree planting in fallow did not improve the phosphorus status the soil, however, the available phosphorus in the plant was improved for the following species: *A. mangium*, *G. sepium* and *A. auriculiformis*. For all improved fallows combined, soil organic matter content was 8.3 mg g^{-1} against 7.6 mg g^{-1} for the natural fallow. *G. sepium* and *A. mangium* fallow had the highest organic matter (10 to 11 mg g^{-1}), whereas higher levels of phosphorus in the plant were obtained from the following species: *A. mangium*, *G. sepium*, *P. africana* and *A. auriculiformis*. Therefore, the planting of trees in fallow helped improve some physico-chemical and biological soil properties compared to natural fallow namely mycorrhizal activities through the number of spore of mycorrhizal fungi, soil porosity, soil organic matter, available phosphorus, pH, potassium and calcium (Yossi, 2002; Bayala, 2011).

A trial on intercropping has been installed at the research station of Cinzana in 1991 to assess the effect of incorporation of leaves of *Leuceana leucocephala* and *Gliricidia sepium* with or without fertilizer on soil fertility and crop yields. The results showed that the combination of Gliricidia mulch with half recommended dose of fertilizer increased the yield by at least 100%. The mulch of *G. sepium* regulated the soil pH and reduced mineralization of soil organic matter (Sidibé et al., 1997; Sidibé and Goïta, 2009). Despite of the efficiency of the technology, its transfer to rural farmers poses many problems (Sidibé and Goïta, 2009).

From an improved fallow research conducted in southern Sudanian zone, Yossi et al (2002) found that the most productive species in terms of total biomass and leaf biomass, 5 years after planting with a spacing 2X2 were *Pterocarpus erinaceus* (18 t ha^{-1}), *Parkia biglobosa* (15 t ha^{-1}), *Gliricidia sepium* (12.6 t ha^{-1}), *Albizzia lebbeck* (12.4 t ha^{-1}) and *Prosopis africana* (9.1 t ha^{-1}). The highest content of nitrogen was obtained in the leaves of *A. lebbeck* (2.84%), *Gliricidia sepium* (2.69%), *Acacia senegal* (2.60%), *Pterocarpus erinaceus* (2.14%), *Prosopis africana* (2.01%) and *Parkia biglobosa* (1.85%). All well adapted species in the southern Sudanian zone are also good fodder trees (Bayala, 2011). This leads to a multiple demands for biomass for feeding livestock or maintaining soil productivity and then tradeoffs farmers have to make.

Trials were installed in farmers' field in Ouelodjedo (Koulikoro region) to assess the impact of mycorrhization and fallow age on growth performance and improvement of soil fertility. Species and age factors showed significant effects. Among the species tested, *Ziziphus mauritiana* displayed the best growth performance and showed the highest percentage of mycorrhizal infection (personal experience). Moreover, the growth of trees was higher in 20 years fallow age. This can be explained by the fact that soil fertility was higher in follows of 20 years old than those of 10; 5 years and permanently cultivated plots (Yossi et al., 2002).

Gliricidia sepium was tested on farm conditions in the fields of 5 farmers in Katibougou and Cho (Koulikoro region). The treatments used were Gliricidia plantation with the application of nitrogen (0, half dose and a dose). There was no significant difference between treatments after two cropping seasons (Thienou, 2005; Dembélé, 2006). These results may be explained by high variability of the data due to large differences in the soil fertility as well as the limited number of replicates (Bayala, 2011).

The results of a trial conducted in the village of N'goukan (Koutiala) indicated that *Gliricidia sepium*, *Acacia senegal* and *Pterocarpus erinaceus* survival rates were highest in pure plantation or associated with *Stylosanthes hamata*. The highest maize yields were obtained in plots planted with *G. sepium* alone or in combination with *S. hamata* with 2.53 t ha^{-1} and 2 t ha^{-1} respectively (Yossi et al., 2002). The results showed the importance of applying the recommended dose of nitrogen when cropping maize in the first year after fallowing (Sanogo, 1997). In four villages of Nafanga commune, 2 tree species (*Gliricidia sepium*, and Leuceana leucocephala) associated with either *Stylosanthes hamata* or *Mucuna sp.* were compared with sole sorghum. The introduction of nitrogen fixing trees resulted in grain yield of 2.7 t ha^{-1} during 3 cropping seasons compared to 900 kg ha^{-1} for sole sorghum.

Kaya (2004) evaluated the production (wood, leaf biomass) of tree species supporting the cut after two years of fallow and the impact on grain yield of sorghum at the research station of Samanko (Bamako) in Mali.

From Table 10, we can see that species such as *Senna siamea*, *Acacia colei*, *Gliricidia sepium* are more efficient in wood and leaf biomass production. After two years of cultivation of fallows of two years old, the highest sorghum yields were obtained under fallow of *Acacia angustissima*, *Gliricidia sepium* and *Albizzia lebbeck*.

Table 10: The production (wood, leaf biomass) of tree species supporting the cut after two years of fallowing and the impact on sorghum grain yield at Samanko research station (Bamako) in Mali

Species	Wood (T ha-1)	Leaf Biomass (T ha^{-1})	Grain Yield (kg ha^{-1})	
			2002	2003
Senna siamea	16.84	19.13	779.8	1458.3
Senna spectabilis	6.27	9.27	2082.3	1319.4
Gliricidia sepium	13.26	12.18	1938.3	1250.0
Flemengia	2.71	7.88	1635.8	787.0
Acacia	7.43	6.36	2211.9	856.5
Acacia colei	13.09	16.65	294.2	810.2
Albizia lebbeck	4.73	4.84	1666.7	1018.5
Cassia sieberiana	6.86	9.21	954.7	787.0
Jachère naturelle	0.00	0.58	1249.0	810.2
Culture continue	0.00	0.21	1129.6	463.0

In the Sudanian zone two factors limit the extension of leguminous trees and herbaceous fallow in short-term:

- Open grazing of animals during the dry season;
- Large amount of seed required.

Kass et al. (1993) reported that the reasons for the adoption of improved fallows are more economic than ecologic and this means looking for high-value market products (wood, fruits ...). Obtaining a significant annual income from the fallow may justify the increase in its duration and this may improve its potential to restore soil fertility.

Assisted Natural Regeneration (ANR)

We speak ARN when farmers actively protect and manage coppices (wildlings) in their fields in order to (re-) create woody vegetation. It concerns in most of the cases economically valuable species (Lawarnou et al. 2006). It is called ARN to distinguish this practice from reforestation or trees plantation and management of natural forest stands.
Lawarnou et al. (2006) conducted a survey in the Zinder region of Niger where ANR is very well developed. The four main tree species deliberately protected and ranked according to farmers' preference are *Faidherbia albida*, *Adansonia*

digitata, *Prosopis africana* and *Piliostigma reticulatum*. This natural regeneration of crop fields had many impacts on: income (sale of baobab leaves, wood and fodder); the environment (microclimate improvement and reduction of wind erosion); agriculture (soil fertility restoration); livestock (more forage because of gao pods (*F. albida*); food security (sale of timber by poor families made them less vulnerable during lean periods); nutrition (basins in the region produce a lot of vegetables); women (the time taken to collect firewood decreased sharply) and youths (cutting and transporting wood provide some income).

The members of Barahogon association in Bankass in Mali practiced ARN since 1999. The results showed a significant regeneration of trees in millet fields and short term fallow with a density of 250 trees ha^{-1}. Among the regrowth surveyed, 82% were *Combretum glutinosum*, but overall 35 of the 49 most useful species of trees, grasses and wild animals identified were perceived to be increasing. Soil protection and fertility maintenance were the key motivation for this technology to the majority of farmers interviewed. Other secondary benefits are: timber and firewood to meet their own needs, tree leaves and grass for fodder, the income generated by the sale of various products and the protection of young millet plants from water and wind at the start of the rainy season (Allen et al., 2009). Allen et al. (2009) and Faye et al. (2010) hypothesized that poorer farmers may be more motivated than richer ones to adopt better the technology given the fact that it is a low cost solution and that exploitation of wood and non- timber forest products (NTFPs) may contribute to improve their livelihoods.

Crop Roatation, Association Cereals- Legumes

In order to improve the soil fertility and animal feed, several associations cereal-legume were tested. Thus, depending on the area, sorghum/cowpea associations, millet/cowpea, maize/cowpea, sorghum/groundnut may be found in farmers' fields. Associations sorghum/pigeon pea, millet/pigeon pea were also tested. Seed production and mechanization of sowing (for legumes) are the main constraints of maize/cowpea and cereal/pigeon pea associations. Concerning cereals-legumes associations, Charpentier et al. (1991) suggested short-cycle cereals with long cycle legumes with creeping stems. In this type of association, with 30 days between the sowing dates, competition between the two crops is minimized, the dry matter production is maximized and nitrogen fixation, soil cover, weeds control and biological life (fauna and flora of the soil) are improved.

Bagayoko et al. (1996), Goita and Sidibé (2009) studied at the Research Station of Cinzana (Ségou) the fertilization and the rotation of two crops which are millet [*Penisetum glaucum* (L.) R.Br] and cowpea [*Vigna unguiculata* (L.) Walp]. The results of this research indicated that the application of 40 kg N ha^{-1} and cowpea rotation increased grain yield and the biomass of millet stalks.

Measures of Crop Fertilization: Mineral and Organic Fertilizers

Soil fertility decline is often observed due to the depletion of minerals (mineral deficiencies) and acidification of land. Nitrogen and phosphorus mineral are the most used for cereals fertilization. For cotton, other nutrients such as potassium, boron and sulfur are used in the formula advised by extension services. Organic fertilizer based on the use of various organic matters, has limited use by the low availability of organic products. Access to credit remains a key condition for better use of organic and mineral fertilizers.

Crop Mineral Fertilization

Nitrogen

It is mainly provided in the form of urea or complex fertilizers. Tests of the nitrogen sources showed that ammonia forms are the best. Significant quantities of urea are used in irrigated rice cultivation. Based on farmers, the dose per hectare varies from 200 kg to 400 kg. Before the intensification, the use of urea was estimated to 50-100 kg ha^{-1}. Nitrogen addition in the case of straw exportation is balanced, with 250 kg ha^{-1} of urea, for a yield of 5 t ha^{-1}. In rainfed conditions, doses of urea per hectare vary from 0 kg to 50 kg for millet, sorghum and cotton and 100 to 150 kg for maize.

Phosphorus

In irrigated rice, the average dose of phosphorus used is 100 kg $ha^{-1}$of ammonium phosphate. Market liberalization has led to the introduction of other types of fertilizers.

With a target yield of 5 t ha^{-1}, the phosphorus balance is positive, even if the straw is exported. For rainfed crops, phosphorus is supplied in the form of complex with a dose of 100 to 200 kg ha^{-1}. The use of Tilemsi Natural Phosphate rock (TNP) is low, due to its unfavorable physical characteristics. The average dose recommended is 300 to 500 kg ha^{-1} for 3 years.

Potassium

Potassium is used mainly on rainfed crops, through the complex fertilizer. But, it has always been excluded from the fertilization formula of rice. Even intensification has not changed this situation. Recent studies show that potassium use in some rice cultivation areas is crucial in improving production. Current research shows that it is necessary to start thinking about the inclusion of potassium in the fertilization policy, because with the competition between agriculture and livestock, exports of crop residues are very important.
Indeed, the balance potassium for a yield of 5000 kg ha^{-1} is very negative when crop residue is not incorporated.

Trace Elements: Zinc, Boron and Sulfur

Zinc is a micronutrient whose deficiency is very common in rice. The zinc sulphate fertilizer is most often used to correct this deficiency.
Sulfur and boron are exclusively used in the fertilization of cotton in the form of cotton complex.

Organic Fertilization

The use of organic matter (manure, compost, garbage, etc.) and local fertilizers (phosphates, gypsum, calcite, and dolomite) constitute good potentialities in the context of improving crop production and soil physico-chemical properties.

Improved Parks

This is a fixed enclosure for the animal parkage, where stems, straw or other plant material in the form of litter are brought to produce manure (Bosma & Jager, 1992). Maize straw used as litter can efficiently absorb ammonia to reduce losses up to 85% and 50% in cow dung and dung-urine mixture respectively (Nzuma & Murwira, 2000). Research aims to improve soil organic status, focused on manure production techniques. Thus at the research station in Cinzana, by incorporating 24 kg of litter/animal/ month, it was possible to produce in 6 months, 1600 kg of manure /animal with 42% of moisture and a C/N ratio equal to 26. Manure with a high C/N ratio, causes a lack of nitrogen in plants in poor soils. So, it is very important to produce manure with a low C/N ratio. Many forms and sources of organic fertilizers were used in order to improve soil fertility. These fertilizers are of various compositions (Table 11). Thus the analysis of 281 samples of organic manure of all types taken in southern Mali gave mean values presented in Table 12. A ton of organic manure provides only 9.7 kg N, 1.7 kg P and 12.8 kg of potassium (Kanté, 2001).

Table 11: Chemical Composition of Organic Manue (all types)

Analysis	Mean value ± standard deviation	Coefficient of variation (%)
Organic Matter	38 22	58
%N	0.97± 0.53	55
%P	0.17± 0.07	45
%K	1.28± 0.9	70

Some parks are accompanied by improved compost pit where the decomposition of manure continues after cleaning the park. In addition to improved parks, many farms continue to produce crumb from traditional parks where the litter is not used. In addition to manure, research has worked on the production of compost.

The DRSPR-Sikasso has produced a factsheet on composting. Farmers, beside manure and compost produce large amounts of garbage in the open air or by composting.

Overall, 67% of farms in the CMDT zone produce organic matter of different origins (improved park, traditional park, manure pit, compost, manure heap, etc.). The most widely used technique is the compostage (28% of farms), followed by the traditional park (26%), other techniques (15%), the manure pit (11%), improved park (9%) and the stable manure heap (6%) (Kanté, 2001). The number of compost peat increased from 15 000 in 1995 to about 40 000 in 1999 (CMDT, 2000). However, just over a third of the cotton fields (38%) received organic manure. The best equipped farms (type A and B) produce more organic manure than the less equipped having fewer animals (types C and D) (CMDT, 1999). Organic and mineral fertilizers are used by 90% of farms compared to 7% and 2% of farms using only mineral fertilizers and organic manure respectively (Giraudy & Samaké, 1995).

Incorporation of Crop Residues and Green Manure

Fallowing for more than 10 years allowed the restoration of soil fertility. In some areas in southern Mali and precisely in the old cotton basin, land is used almost permanently. But after 10 years of cultivation of land with poor soils of southern Mali and without incorporation of crop residues, there is a loss of 24-46% of the initial soil organic matter reserve (Kanté, 2001). Crop residues with low C/N are a major source of nutrients for plants. They can serve as efficient means of maintaining soil organic matter, if they are returned into the plots where they have been produced (Kanté, 2001). Unfortunately, less than 10% of the residues are incorporated in the area of Koutiala (Camara, 1996). Bationo et al. (1993) reported a reduction by 59% of sand horizontal transport after an application of 2 t ha^{-1} of crop residues. The main constraint to crop residue incorporation is the lack of means for mechanical grinding. At ICRISAT such residues has reduced soil surface temperature (1 m depth) from 48.5 to 39.3 °C (Bationo et al., 1993). However, for a better utilization of organic matter, it is necessary to take into account their quality: % N, C/N ratio, (lignin and poly-phenol)/N ratio.
It should be noted that crop residues as well as manure can not correct the deficiencies of nutrients from their environment. In order to correct this deficiency, it is required to bring nutrients from outside the system.

Yossi et al. (2002) studied the influence of pruning and incorporation of *Prosopis africana* leaves with or without NPT on the performance millet in the village of Lagassagou in northern Sudanian zone. The incorporation of *P. africana* leaves had a significant effect on millet grain yield (1.86 t ha^{-1}). This treatment was followed by plots under pruned *P. africana* without incorporated leaves (1.23 t ha^{-}

^{1}). The lowest yield was obtained in plots without tree with or without incorporated leaves as well as on plots under unpruned trees without incorporated leaves (0.5 t ha^{-1} and 0.8 t ha^{-1} respectively). Crop yield reduction under unpruned trees was estimated at 60%.

The effect of green manuring with leaves of *Tithonia diversifolia* on yields of *Amaranthus viridis* and *Zea mays* (maize) in the gardens of Lafiaboufou and Samaya was evaluated by ICRAF. The green manure *T. diversifolia* at levels of 2.5 to 5 t ha^{-1} in combination with phosphate (100 kg ha^{-1}) improved the growth and double the yield of *A. viridis* and triple the grain yield of maize compared with farmer practice of 10 t ha^{-1} of household garbage (Zerome, 2000). Doumbia (2000) through a survey revealed that species such as *Cassia sieberiana*, *Combretum lecardi*, *Guiera senegalensis*, *Piliostigma reticulatum* and *Crotalaria retusa* are used by farmers as indicators of soil fertility. The effect of applying the biomass of these species with and without phosphate on the performance of maize, cow peas and tomato was tested in Sotuba and Samanko (south Sudanian zone in Mali). Leaves of *C. lecardi* at a rate of 5 t ha^{-1} induced the highest maize yield (4.8 t ha-1), followed by *P. reticulatum*, and *C. retusa* (4.2 t ha^{-1}), *G. senegalensis* (4.1 t ha^{-1}), *C. sieberiana* (3.4 t ha^{-1}) and farmer practice (3.3 t ha^{-1}). The application of 2.5 t ha^{-1} leaves of *C. sieberiana* with 75 kg N ha^{-1} induced the highest number of branches and the highest yield of tomato compared to farmers' practice which performed poorly (Doumbia, 2000).

CHAPTER 4

SOIL PHYSICO-CHEMICAL STUDIES, EVALUATION OF GLIRICIDIA SEPIUM TREES AND SURVIVAL RATE IN THE PLANTATIONS OF THE 20 PILOT VILLAGES

Context

In 2010, Oxfam America's SfC program created an agricultural pilot covering 20 villages. These activities were based on SFC's women interest in learning new gardening and agricultural techniques. Women and men were trained in various soil conservation measures, especially the planting of particular trees species and bushes to help with soil fertility. A short-cycle cow pea variety was also introduced in these villages. In each of the pilot villages, women have been given a collective field on which to try agricultural techniques. Part of the plot is held as a control area with no improvements beyond what would have happened without the pilot. Among the technologies introduced, *Gliricidia sepium* plantation was a success in most of the pilot villages. Pilot villages are located in the circles of Sikasso, Koutiala, Bougouni, Kolokani, Kati and Koulikoro. A soil baseline study was performed in the Gliricidia plots in the 20 pilot villages and this will allow us to track how soil fertility changes over subsequent years. The survival rate and the state of Gliricida trees were evaluated one year after plantations.

Soil physico-chemical studies

100 soil samples were collected from *G. sepium* plots in 20 villages. The samples were analyzed at Soil-Water-Plant Laboratory at the Institute of Rural Economy Sotuba.

Materials and Methods

Soil samples were collected from the 0-20 cm layer in women collective fields (experimental plots and control) where *Gliricidia sepium* trees are planted. There are no *G. sepium* trees in the control plots. In each village, five composite samples were collected (4 samples in women fields and a sample in control plots). It should be noted that four samples were collected in different points in the field and mixed thoroughly to form a composite sample.

The samples were collected using a hoe (daba) or a hand auger. Collected soils were packed in plastic bags and labeled (Plate 1).

The analysis focused on the physico-chemical properties: the particle size with 3 fractions (clay, silt, sand), pH (water), pH (KCl), Pf (2.5, 3.0, and 4.2), moisture soil, soil organic matter (C), nitrogen (N), total available phosphorus and available potassium.

Plate 1. Soil sample collected in women's Cliricidia plantation in Kolokani circle

- **Particle Size**

The soils have coarse and medium texture. The soil texture is sandy in Sananko, fine silt in Fabougou, Biladji, Tinko and Tiecourala, sandy silt in Tabacoro, Soukourani, Soma, Nanicoura, Moribougou and Medina and silt sandy in Lafiabougou, Kouroukanda, Kouloukoura, Babougou, Banabougou, Dalakania, Dani, Dembela and Banankoro[3]. These soils are light and easy to work.

- **pH**

Standard interpretation:

  - pH <5.5 = strongly acid where Al, Fe and Mn are potentially toxic
  - pH = 6.5 = optimum pH for nutrient availability
  - pH = 7.3 = beginning of alkalinity and salinity dominance of Ca
  - pH> 8.2 = beginning of sodium toxicity.

[3] Note that all village names in this report have been changed to protect confidentiality.

The pHs of these soils are: very acidic, slightly acidic and optimum for nutrient availability. Soils of Tabacoro, Tiecourala, Kouroukanda, Kouloukoura, Babougou, Banabougou, Dalakania and Soukourani are close to neutral and this is the optimum pH for the availability of most nutrients. The soils of Soma, Dani, Fabougou, Dembela, Biladji, Lafiabougou and Nanicoura are slightly acidic. On the other side, soils of Tinko, Banankoro, Moribougou and Medina are very acidic. However, the ΔpH [pH (water) - pH (KCl)] is greater than 1 which indicates a potential acidity.

- **Organic Carbon**

Standard interpretation:

- Critical level: 0.6%
- A soil is said organic at 18% of organic carbon.

The organic matter conetnt is a good indicator of soil fertility level. The organic matter contents of these soils are low and situated in the ranges from 0.27% (Sananko) to 1.59% (Banankoro). However, these soils have organic matter contents above the critical level of 0.6% (critical level of structural stability) except those from villages such as Nanicoura (0.32%), Banabougou (0.5%), Dani (0.48%) and Sananko (0.27%).

- **Phosphorus**

Standard interpretation:

- Critical level: 7 ppm.
- There is no application of phosphorus from 20 ppm of P.

Soils in the study areas are very poor in available phosphorus with concentrations ranging from trace in Lafiabougou to maximum in Medina (10.5 ppm). Surprisingly, soils in Tabacoro have high levels of phosphorus (165 to 194ppm). This means that it is not necessary to apply phosphorus to these soils. Trace of phosphorus in a soil means that the phosphorus content is below the detection limit of the instrument used to measure it (0.001 ppm).

Conclusions and Recommendations

Soil depth and texture are important factors that determine not only soil ability to support agricultural crops but also the type of crop to be implemented. The soils have coarse (sandy loam) texture, light and easy to work. Soils are potentially acidic (ΔpH > 1), relatively poor in organic matter and nutrients (especially nitrogen and phosphorus). Therefore it is necessary to properly apply organic and mineral fertilizers as advised by extension services. For cereals, the application of DAP fertilizer during the first years of cultivation is essential due to the fact that on one hand these soils are very poor in phosphorus (except Tabacoro) and on the other hand they have adequate levels of potassium (more than 2 mg/100g of soil).

Evaluation of *Gliricidia sepium* trees and survival rate in the plantations of the 20 pilot villages

Gliricidia sepium trees and survival rate in different plantations are presented in Table 12. It is worthwhile to mention that the survival rate is very good in many plots (plate 2, 3, 4 and 5) partly due to the care given to plantations and also the relining of plants. In most of the villages, the plots are well maintained so the plants are doing very well. In the other side, in few villages the management of *G. sepium* plot is not done correctly (Plate 6).

Plate 2. Women field with sesame in Koulikoro Circle

Plate 3. EPC coordinators and field agent with women in their field in Kolokani circle.

Plate 4.Two SFC agents near a nice Gliricidia tree in women field in Sikasso circle

Plate 5. Gliricidia trees in SfC women's field in Koutiala circle

Plate 6. Even protected Gliricidia tree can be sometimes browsed by animals, Sikasso circle

The survival rate and the state of Gliricida trees were evaluated one year after plantations. *Gliricidia sepium* plantation was a success in most of the pilot villages. The percentage of survival reached 100% for some villages. The lower survival rates (14% in one village and 50% in another) are found in Banamba circle.

Table 12. Survival rate of Gliricidia sepium trees in the plantations of the 20 pilot villages

Zones/Cercles	Villages[4]	Survival rate (%)	Associated crop	Soil sampling dates	Remarks
Sikasso	Moribougou	92	No associated crop	4/11/2012	The Gliricidia plants are healthy. The plot is well maintained. The fence must be done before the end of crops harvest.
Sikasso	Nanicoura	94	No associated crop	03/11/2012	The Gliricidia plants are healthy. The plants are in a very good condition. The field is weeded. A problem exists in the village between the clan of the village chief and the rest of the population. This problem is the result of the mismanagement of Eucalyptus plantations. This problem is actually affecting the management of Gliricidia plantation.
Sikasso	Banankoro	92	No associated crop	04/11/2012	The plot is very well weeded. But most of trees suffer due to animals grazing. There is an urgent need for protection.
Koutiala	Sananko	100	Sorghum	07/11/2012	Sorghum did not work well. Gliricidia trees are doing well.
Koutiala	Tabacoro	100	Sesame	07/11/2012	Sesame worked well. Gliricidia plants are very big and very vigorous.
Koutiala	Medina	100	Sorghum	07/11/2012	Sorghum did work well.

[4] Note that all village names have been changed to protect confidentiality.

					Gliricidia trees are doing well and are very healthy
Bougouni	Babougou	86	No associated crop	31/10/2012	Half of the plots are not cultivated. The control plot is not cleared. Most of the plants are not protected.
Bougouni	Soukourani	100	No associated crop	31/10/2012	The field is not cultivated. The plots are full of herbaceous plants. Gliricidia trees are not at all protected.
Bougouni	Lafiabougou	88	No associated crop	02/11/2012	The control plot is not cleared. The plot is not maintained. Plots are full of weeds. Gliricidia trees are suffering a lot.
Bougouni	Kouroukanda	83	No associated crop	01/11/2012	There are many problems: the road passes through the plot; animals are grazing trees, the plot is not cultivated consequently trees are very small. There is a need of watering.
Kati	Fabougou	100	No associated crop	21/10/2012	Relining focused on three plants that are alive. The villagers decided to change the site due to the fact that they can not grow trees on the current site.
Kati	Tiecourala	100	No associated crop	21/10/2012	There is no protection, so some plants were grazed by animals
Koulikoro	Dalakania	84	No associated crop	17/10/2012	The plot is not cultivated. Relining was done but the plants are very small and there is a need of

					watering
Koulikoro	Kouloukoura	80	Sesame field (very good)	17/10/2012	Relining was done but the plants are very small and there is a need of watering
Kolokani	Dembela	100	Cowpea	19/10/2012	Relining was done correctly
Kolokani	Banabougou	98	Sorghum/cowpea	19/10/2012	The field needs to be weeded and the trees protected; Cowpea should be harvested
Kolokani	Dani	96	Sorghum/cowpea	18/10/2012	Gliricidia trees are doing well and are very healthy.
Kolokani	Soma	100	Peanut	18/10/2012	The plants are healthy and well developed; the site is very good.
Banamba	Biladji	14	Sesame	15/10/2012	Animals are grazing trees
Banamba	Tinko	50	Sesame	15/10/2012	The remaining plants are healthy. The fences around trees are not in good condition.

CHAPTER 5

STUDY ON FARMERS' KNOWLEDGE AND RESOURCES PERSONS' PERCEPTION ON SOIL FERTILITY AND WATER AVAILABILITY IN KOULIKORO AND SIKASSO REGIONS

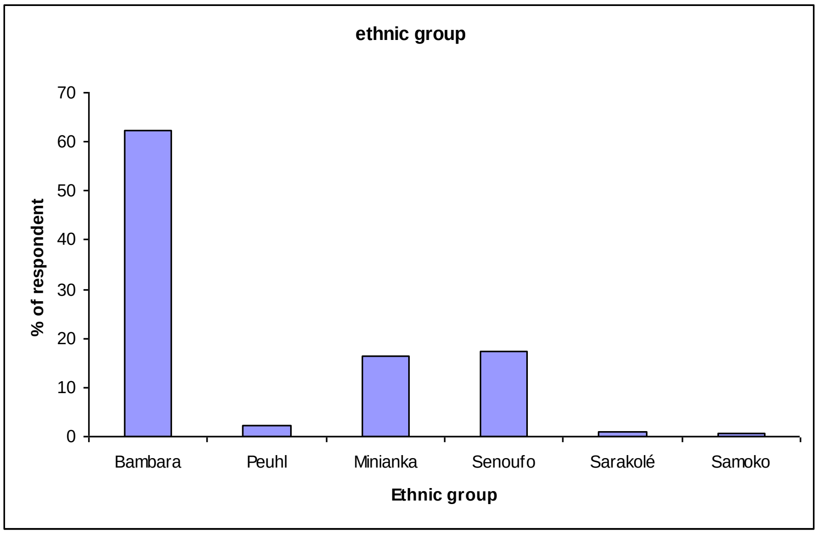
Introduction

The Sahel regions of West Africa are characterized by unique climatic and soil conditions. Rainfall is insufficient and irregular. Wind and water erosion affect the quality of land and its productivity. The agricultural production systems based on annual cereal crop production are vulnerable and production levels cannot adequately feed the growing population. Food security is, therefore, a critical issue in the Sahelian countries of West Africa (Sidibé, 2010). The percentage of the population suffering from malnutrition is estimated at 20%, 36% and 36% for Mali, Burkina Faso and Niger, respectively (FAO, 2003). Cereal production has increased in the last decades, but the per capita cereal production remains the same and the adaptation of new technologies is low (Coulibaly *et al.*, 2007). A significant part of farmers' income is obtained from resource depletion, mining soil and degrading vegetation (Breman *et al.*, 2001). Thus, the current global food crisis is predominantly affecting the Sahelian countries which are already in food deficit situation.

Despite the importance of soil fertility and water availability issues in the life of people in Sahelian regions, little information has been documented on their current use and management by local communities. Therefore, in the present study of Oxfam-America, a base line survey was conducted in Koulikoro and Sikasso regions to illicit farmers' knowledge and practices concerning soil fertility and water availability changes over the past 5, 10, 20 years, the impact on yield, soil variability within a village, size and location of plots according to gender, the vulnerability of households to degrading soils, the speed of land degradation and strategies developed or known to men and women to mitigate soil fertility and water availability depletions.

The ethnic groups found in the two regions are Bambara (62%), Senoufo (17%), Minianka (16%), Peulh (2%), Sarakolé and Samoko (Fig.8). Economic dependency ratio is higher in Koulikoro region (52) than in Sikasso (45). This means that in Koulikoro region each group of 100 active persons supports economically 52 inactive. This ratio is high when compared to the standard situated between 30 and 35.

Firgure 8: Ethnic Groups Found in Koulikoro and Sikassso regions



Materials and Methods

Data Collection

The study was conducted in 10 villages from Oxfam's agricultural Pilot intervention zones. The 10 villages were randomly selected in Koulikoro and Sikasso regions (Table 13). Tools including focus group discussions, structured and semi-structured interview were used during the survey (Plate 7, 8 and 9). All the women who participated to the interview were Saving for Change members, but the men were not members. A total of 178 persons were randomly selected and interviewed (77 in Koulikoro and 101 in Sikasso region). In each village a list of participants' names was written on a piece of paper. The paper was then fold in order to prevent that someone could read it. All the pieces of paper with name are placed in a small basket. The names of interviewees were drawn from this basket with the help of a kid. The ages of surveyed persons were between 19 and 84 years. Among the interviewed persons, 73% were women and 27% men.


Plate 7. Group Discussion in Koulikoro circle


Plate 8. An interview with a woman in Banamba circle


Plate 9. SfC agent interviewing a woman in Sikasso circle

Statistical Analysis

Statistical Package for Social Science SPSS version 16 for Windows was used to analyse the data. Frequencies of responses were analysed through descriptive statistics.

Table 13 Number of Interviews in 10 Villages (SfC)

Circles	Villages[5]	Group Survey	Individual Survey	Total
Sikasso	Moribougou	2	2	**25**
Sikasso	Nanicoura	2	20	**22**
Koutiala	Sananko	2	26	**28**
Bougouni	Lafiabougou	2	13	**15**
Bougouni	Kouroukanda	2	19	**21**
Kati	Fabougou	2	10	**12**
Koulikoro	Kouloukoura	3	15	**18**
Kolokani	Banabougou	2	24	**26**
Kolokani	Dani	2	18	**20**
Banamba	Biladji	3	10	**13**
Total		**22**	**178**	**200**

Results

Figure 9 shows the distribution of fields in the toposequence in the pilot villages according to respondents. It appears that 43% of fields are situated in the lower part of the toposequence while 33% are in medium and 24% in the top. Figure 10 shows the major soil types according to farmers found in their fields in Koulikoro and Sikasso regions. These soil types are: clayey (34%), sandy (27%), loamy (20%) and gravely (19%).

[5] Note that village names have been changed to protect confidentiality.

Figure 9 Field Distribution in the Toposequence

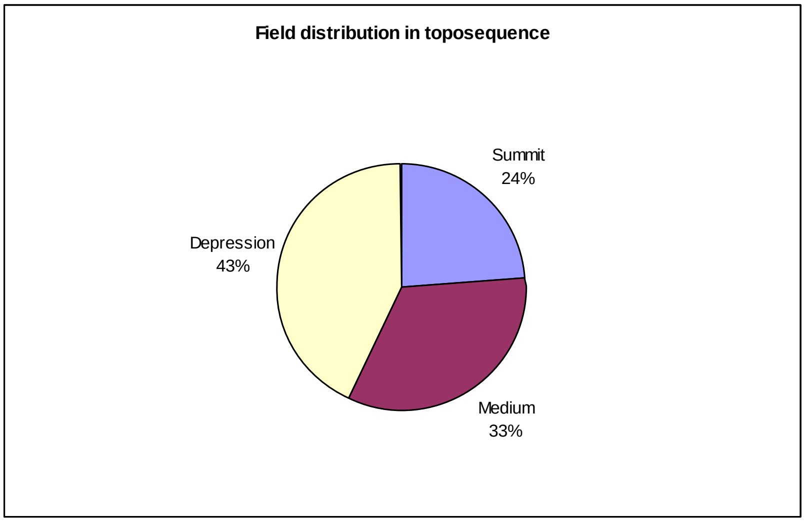
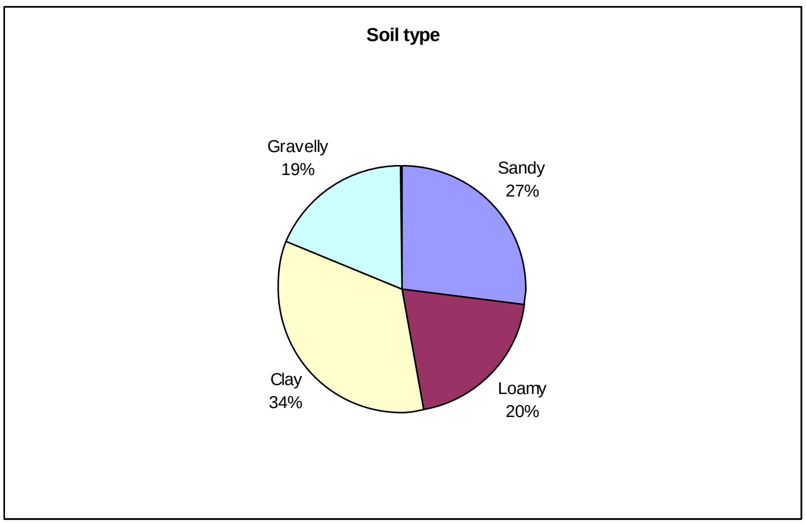


Figure 10 Soil Types Found in Farmer's Fields



Soil Fertility According to Farmers

Figure 11 shows the reported levels of soil fertility in the fields in Sikasso and Koulikoro regions. A high majority of respondents reported that fields' soils are not fertile (84% in Sikasso and 62% in Koulikoro region). 29% of respondents in Koulikoro reported that their soils have a medium fertility while it was stated by only 15% in Sikasso. A very small proportion (9% in Koulikoro and 1% in Sikasso) reported that the soils have good fertility. In the villages (Fig.12), the majority of respondents reported that the fertility is very low in their fields. From figure 12, we can see that it is in Fabougou that more than half of the respondents reported a medium soil fertility of their fields.

Figure 11 Reported Soil Fertility Levels in the Fields in Regions

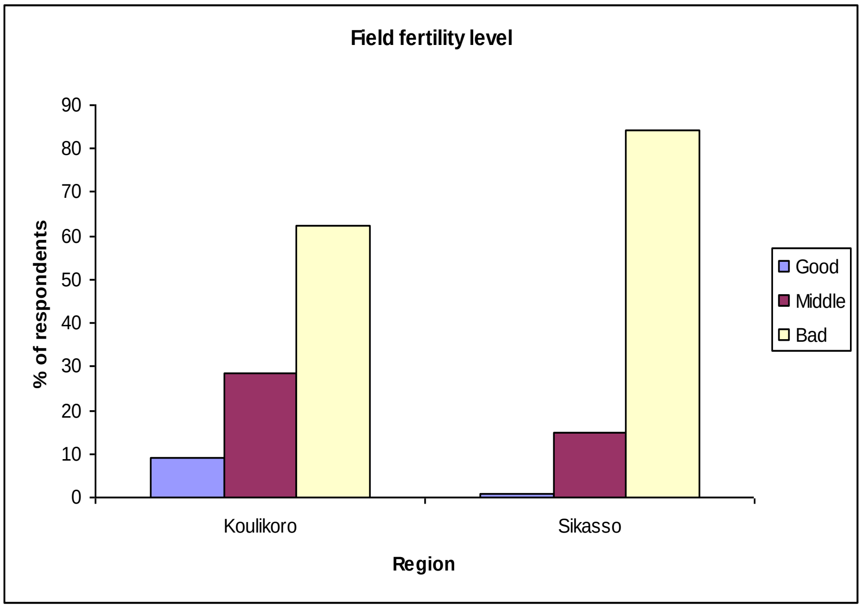
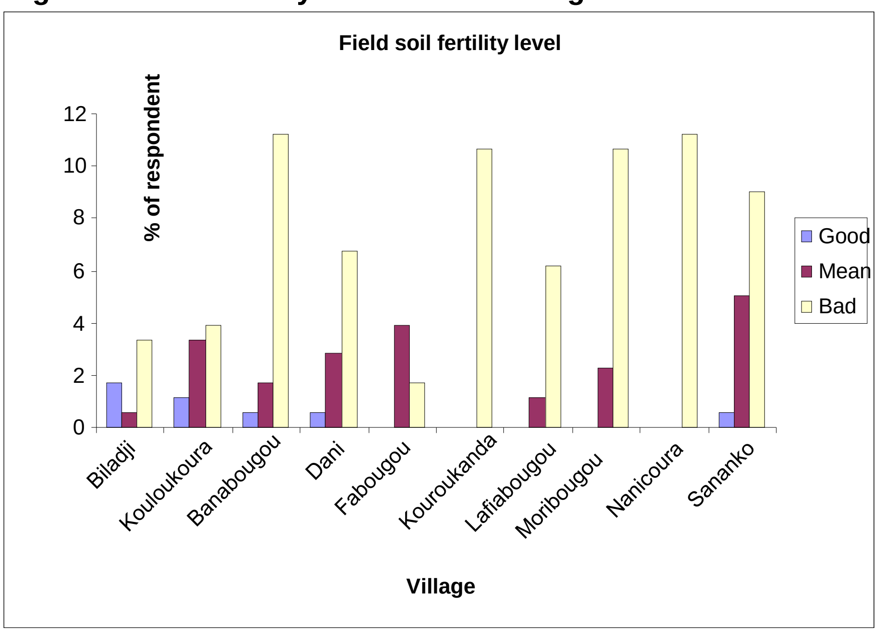


Figure 12 Soil Fertility Levels in the Villages



The high majority of the respondents are aware about soil fertility change in Koulikoro (99%) and Sikasso (96%) regions (Fig.13). The same awareness of respondents was reported in the villages (Fig. 14).

Figure 13: Respondents Awareness of Soil Fertility Change in the Regions

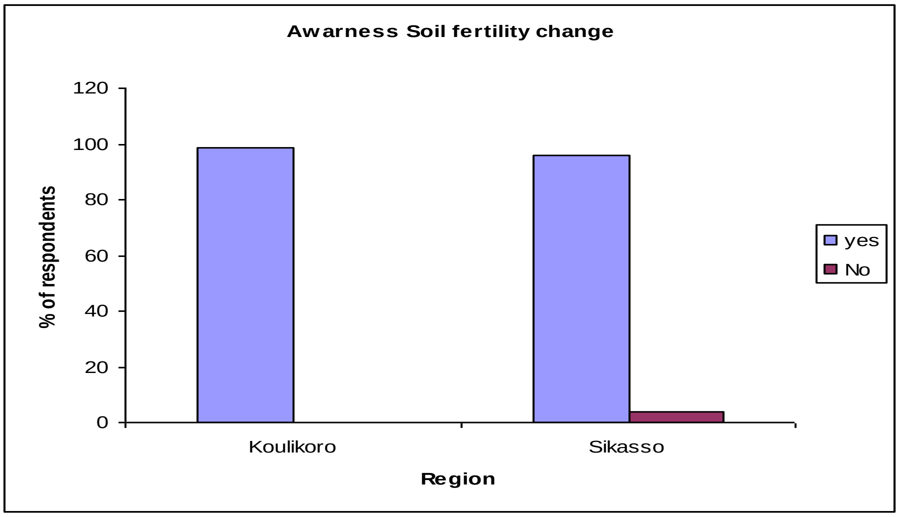
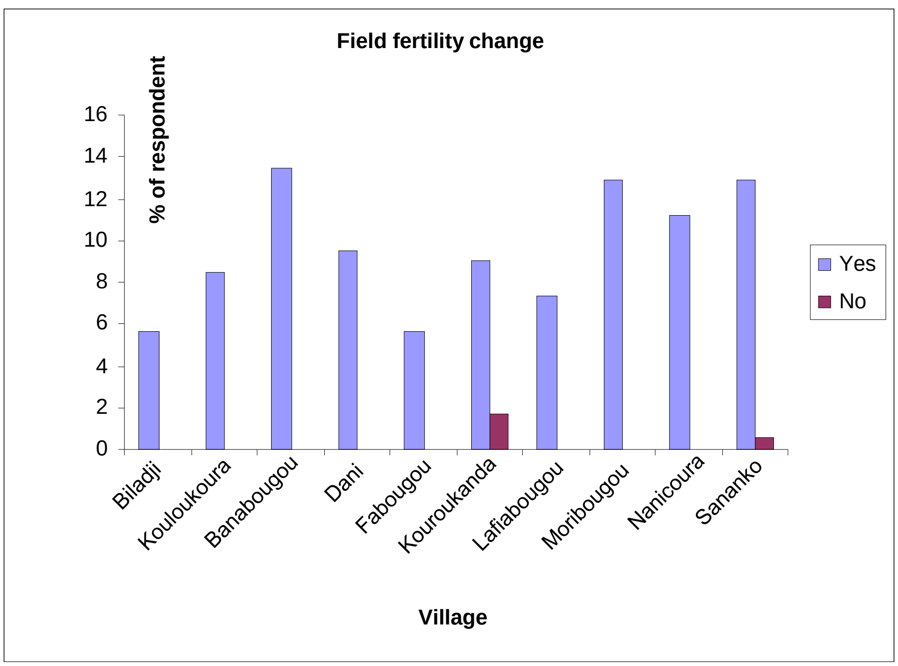


Figure 14 Respondents Awareness of Soil Fertility Change in the Villages



Concerning the soil fertility status (Fig 15), a high majority of respondents (100% in Sikasso and 82% in Koulikoro) reported a decline of the soil fertility. At village level, it is only in Banabougou (Fig. 16) that only 3% of the respondents mentioned an increase of the soil fertility. In response to the question for how long farmers perceived a decline in soil fertility, 53% of respondents in Koulikoro region reported 5 years, 35% reported 10 years and 12% 20 years. It could be interesting to look whether the participants age influence their response to this question but unfortunately this aspect was not taken into account.

Figure 15 The Reported Soil Fertility Status in the Regions

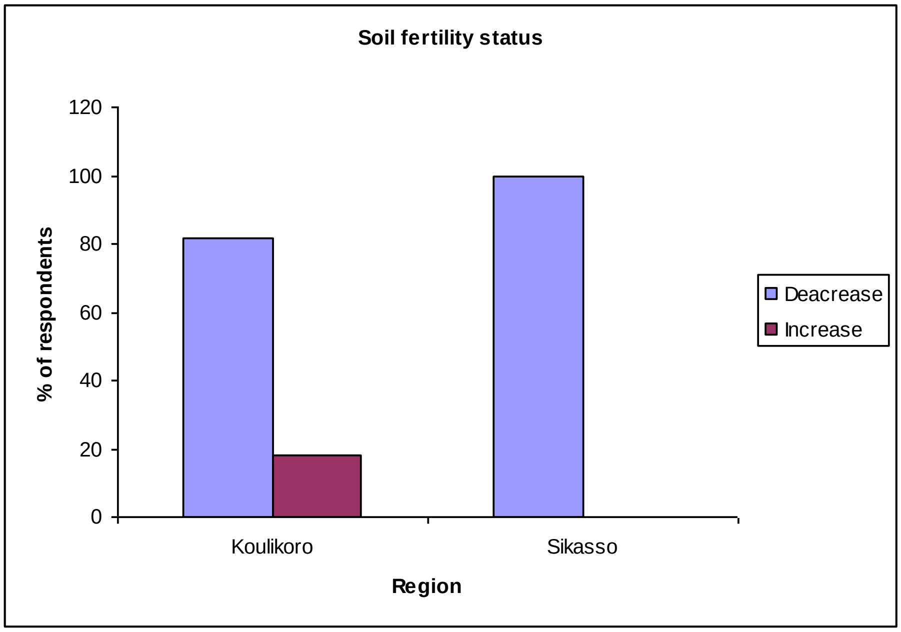
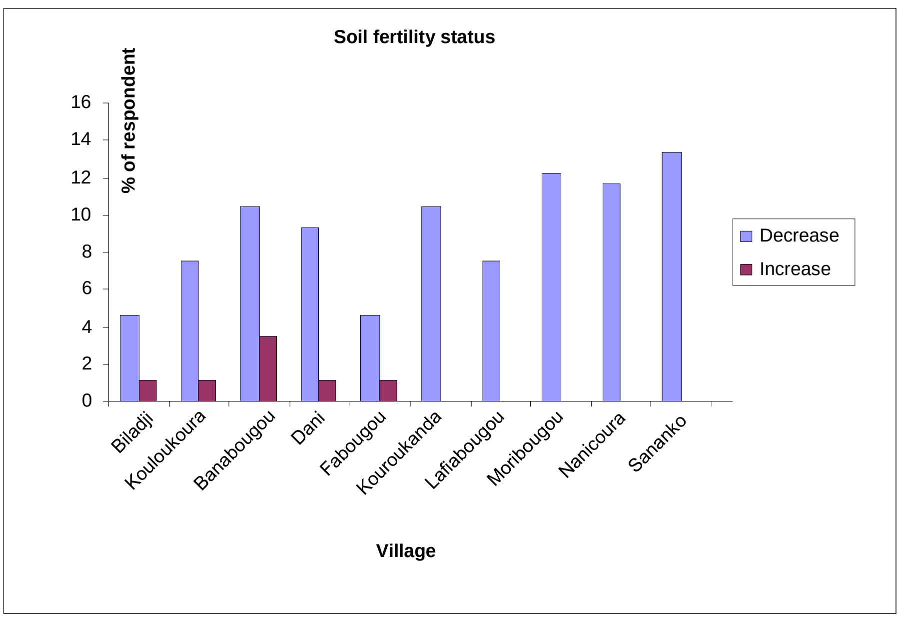


Figure 16 The Reported Soil Fertility Status in Villages



In Sikasso region, 32% of respondents reported 5 years, 35% reported 10 years and 34% reported 20 years (Fig. 17). At village level, the perception of soil fertility decline followed the same trend as the regions (Fig. 18).

Figure 17: Number of Years of Soil Fertility Decline in the Two Regions

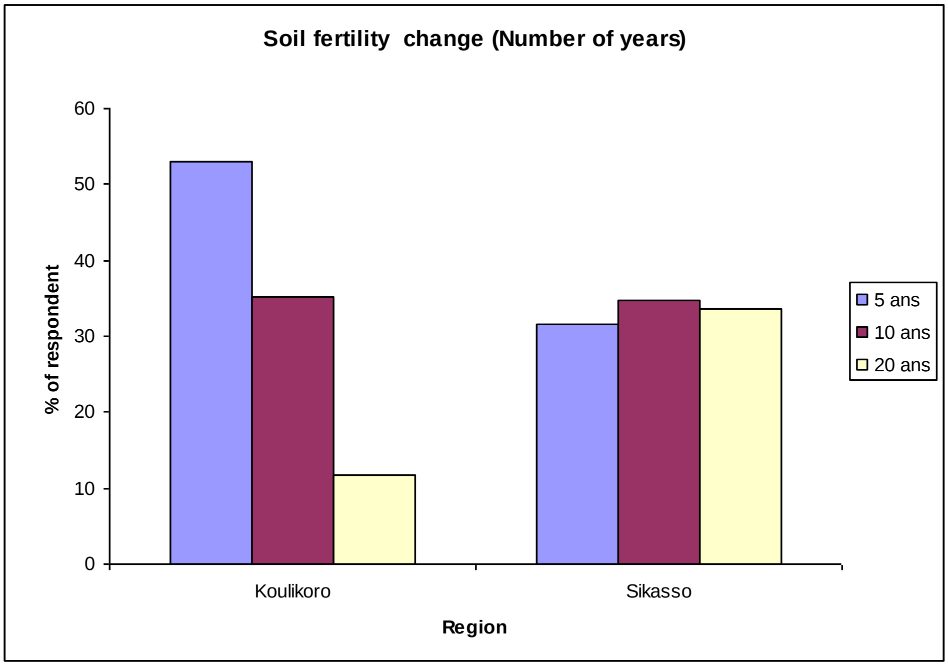
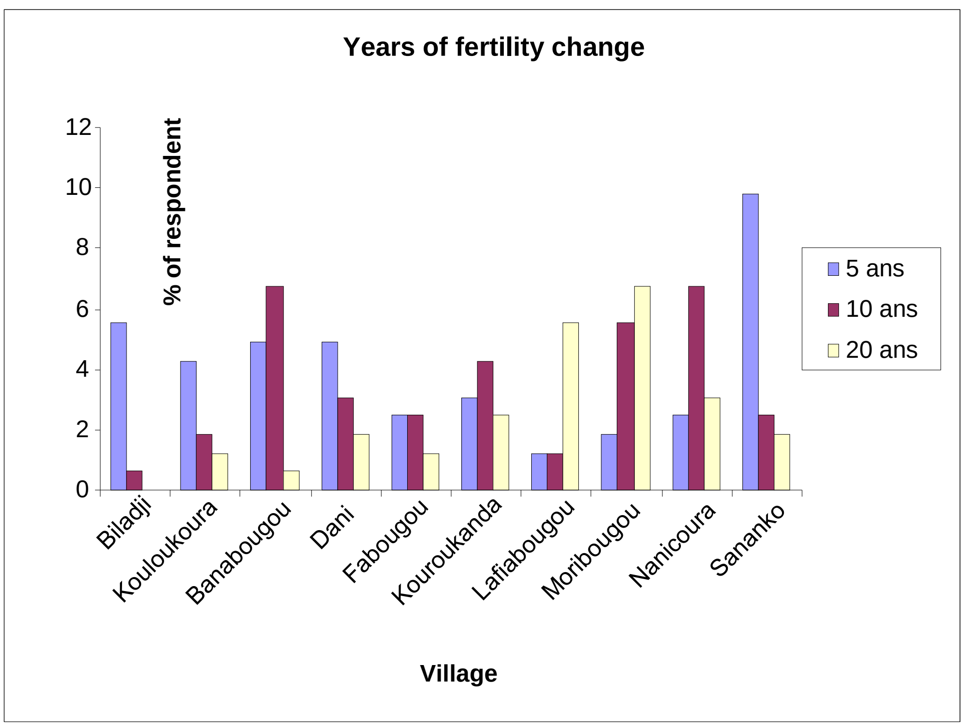


Figure 18: Number of Years of Soil Fertility Decline in Villages as Reported by Respondents



Overexploitation of fields is perceived as the main cause of soil fertility decline. In Sikasso region, 86% of respondents mentioned that field's overexploitation is the main cause of soil fertility decline while it was 66% in Koulikoro (Fig. 19). In some villages such as Lafiabougou and Nanicoura, 100% of respondent reported overexploitation as the main cause of soil fertility decline (Fig.20). It is important to mention that participants were asked an open-ended question.

Figure 19 Field Overexpolitation as a Cause of Soil Fertility Decline in Regions

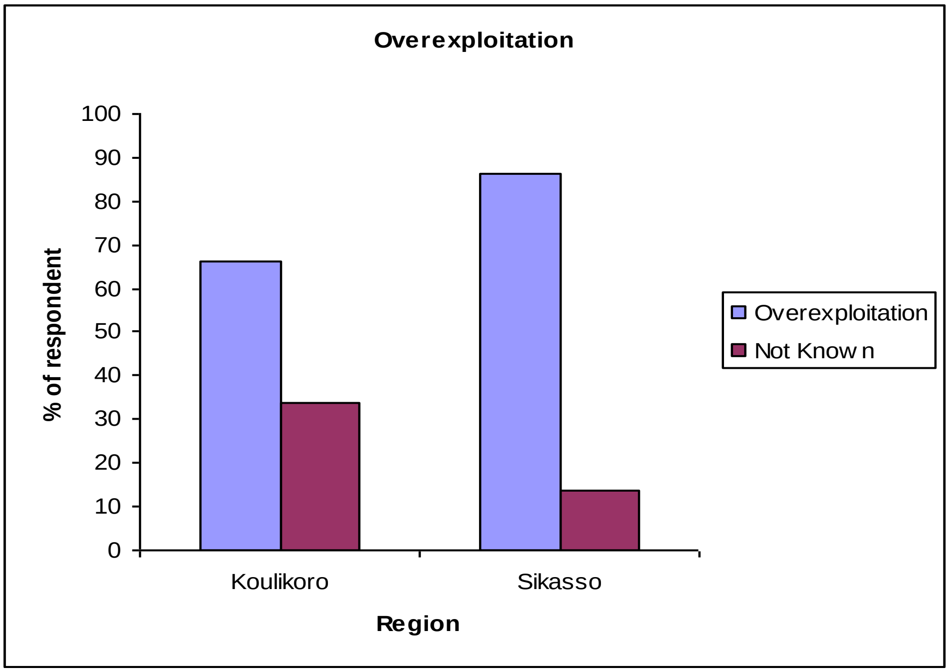
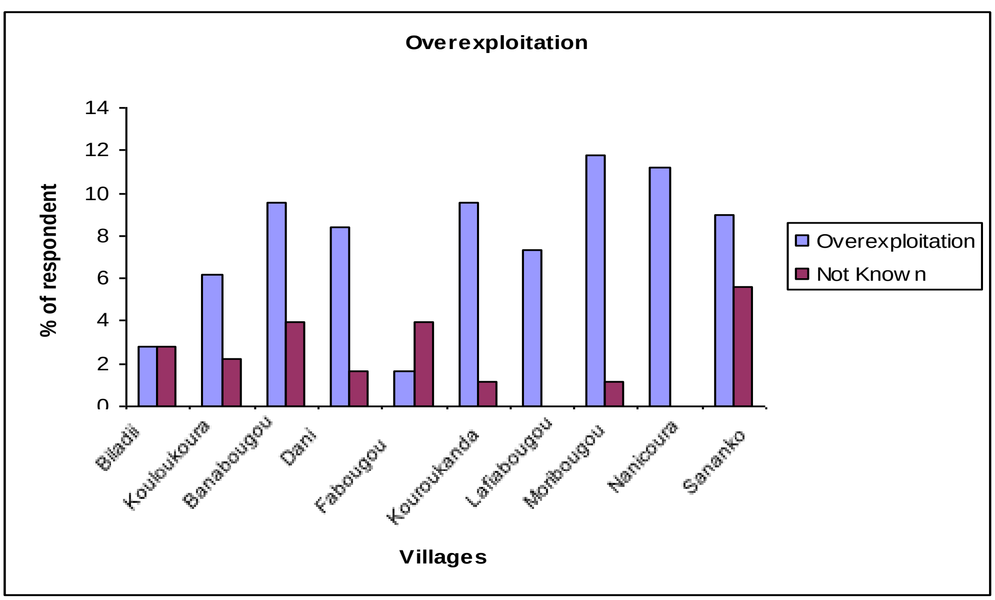


Figure 20 Field Overexploitation as a Cause of Soil Fertility Decline in Villages



Soil erosion is perceived as a cause of soil fertility decline by 44 and 22% of respondents in Sikasso and Koulikoro regions respectively. More than half of the respondents in Lafiabougou, Sananko and Fabougou villages (Fig. 21) reported that erosion is one of the main causes of soil fertility decline.

The lack of resources was mentioned by 29% and 41% of the respondents in Koulikoro and Sikasso regions respectively (Fig. 22).

Figure 21 Erosian as a Cause of Soil Fertility Decline in Villages

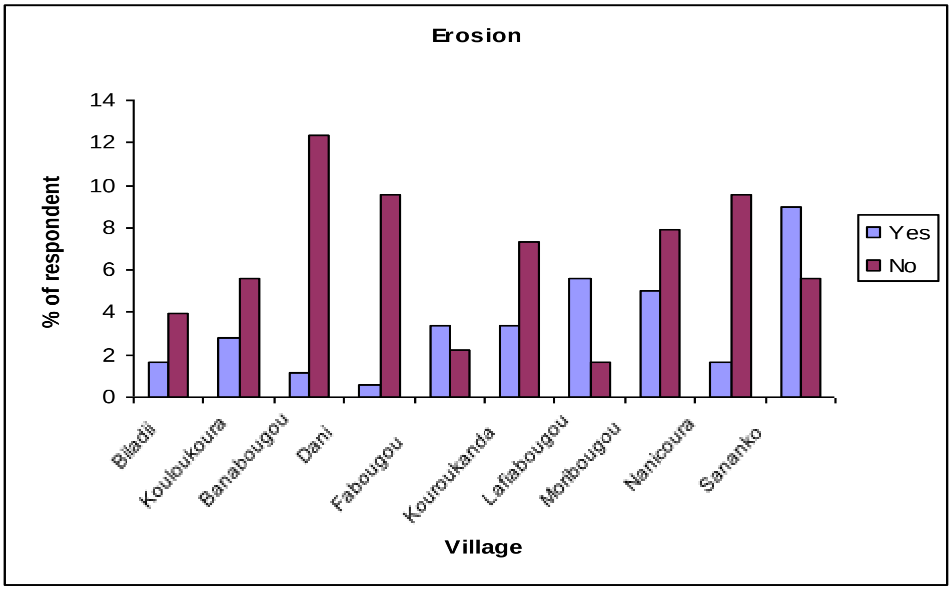


Figure 22 Lack of Resources as a Cause of Soul Fertility Decline in Regions

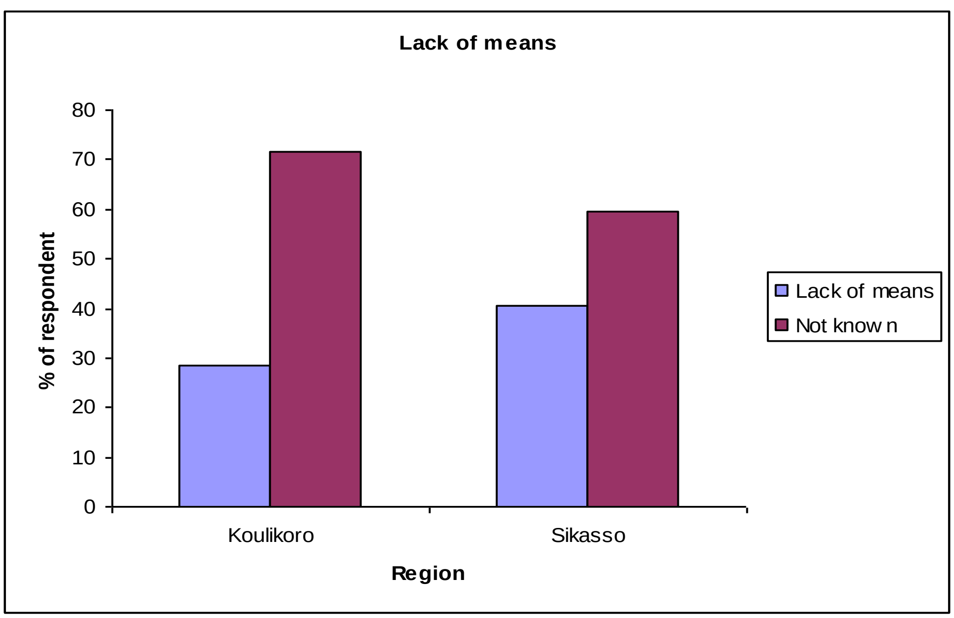


Figure 23 shows the impact of soil fertility decline on crop production in the two regions. 96% and 81% of the respondents reported a decrease in crop production when there is a decline of soil fertility in Sikasso and Koulikoro regions respectively. In all the villages surveyed, the majority of respondents mentioned that there will be a decrease in crop production when soil fertility declines (Fig. 24).

Figure 23 Impact of Soil Fertility Decline on Crop Production in the Villages

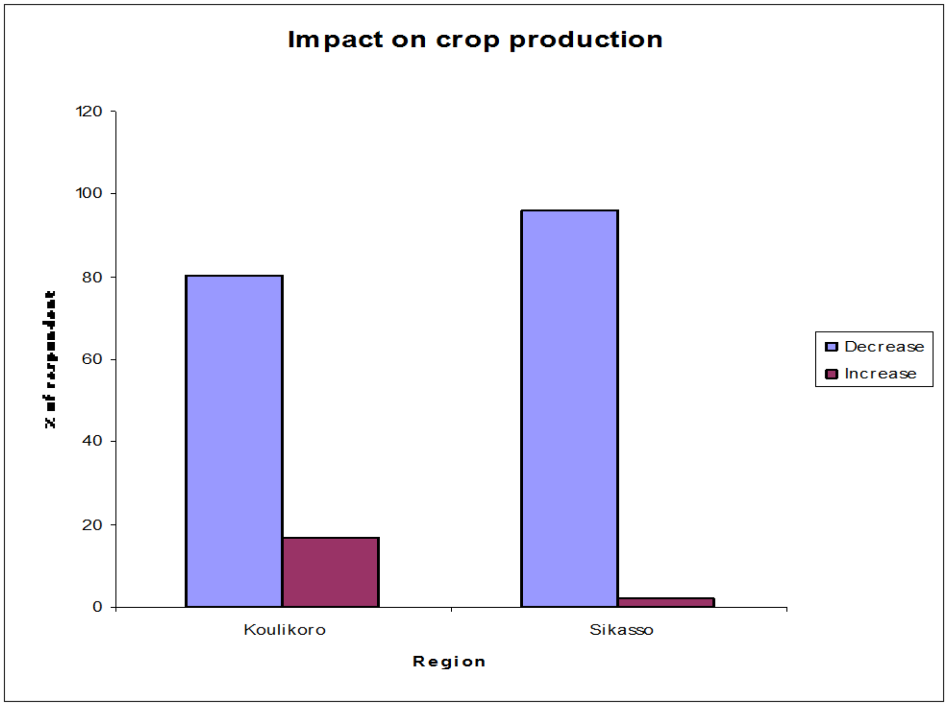
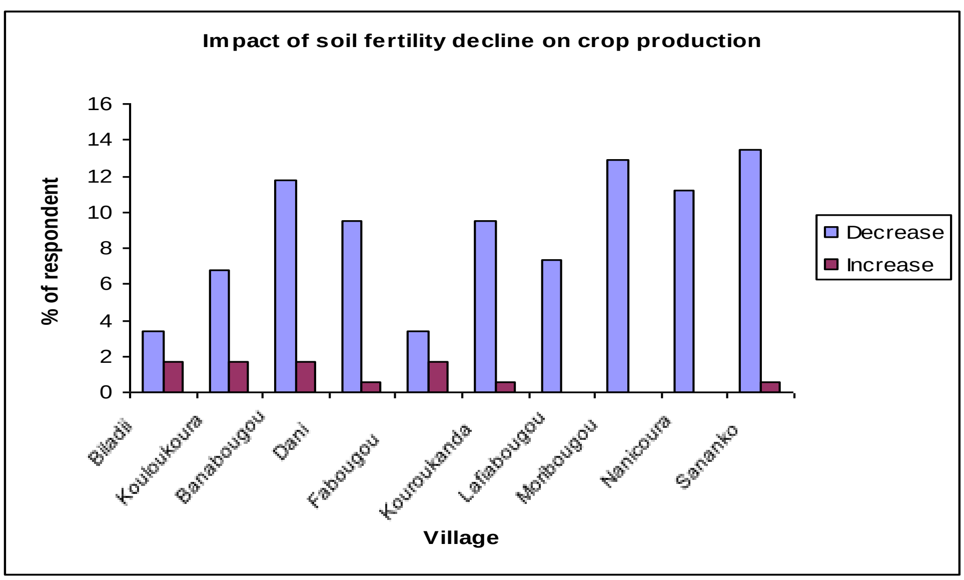


Figure 24 Impact of Soil Fertility Decline on Crop Production in the Villages



In response to the question whether poorer soils are being degraded faster or slower than richer soils, a high majority of respondents reported that poorer soils are being degraded faster than richer soils (Fig. 25 and 26).

Figure 25 Soil Degradation of Poorer Soils

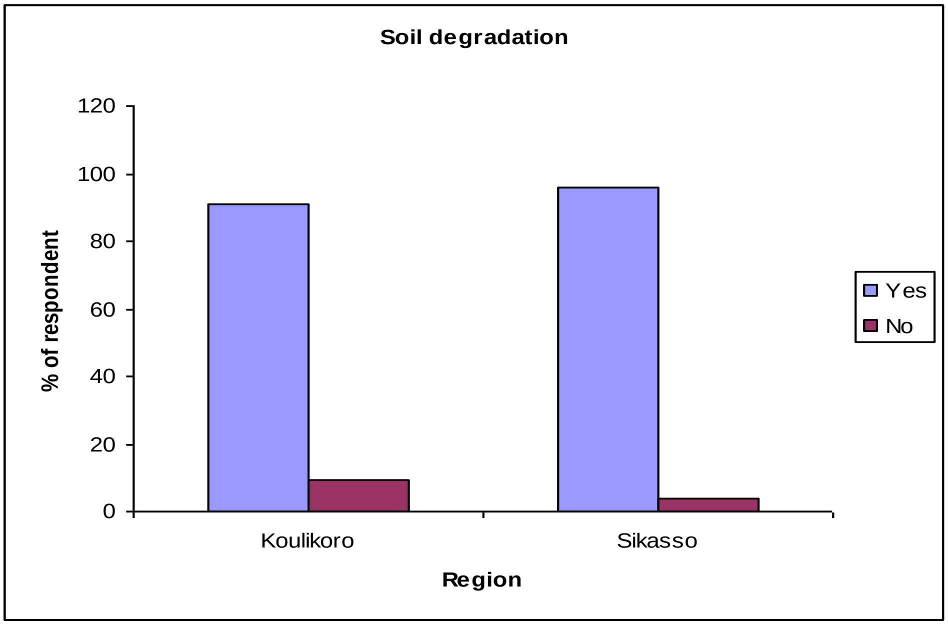
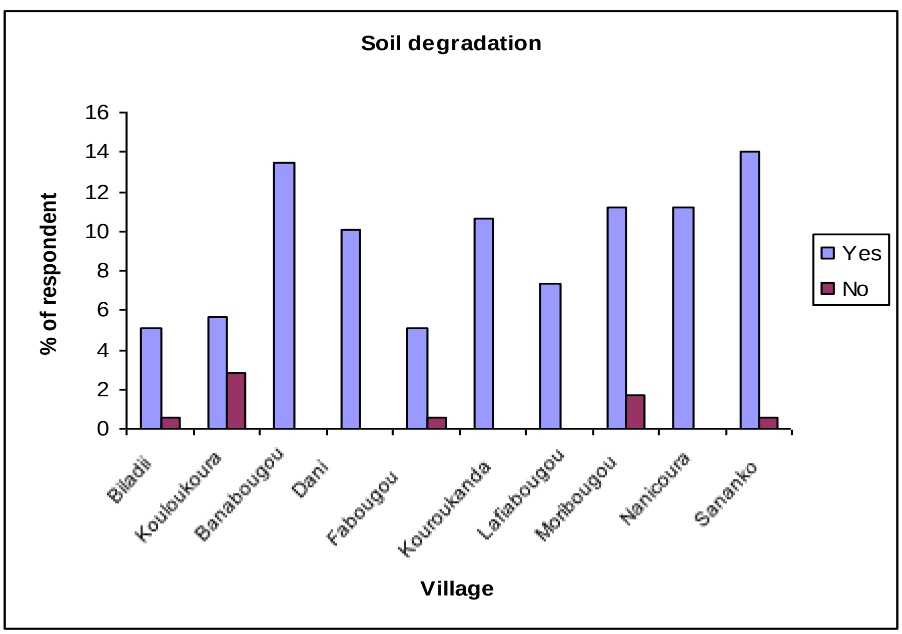


Figure 26 Soil Degradation of Poorer Soils



Concerning the vulnerability of households to degrading soils (Fig. 27 and 28), a high majority of farmers (92% in Koulikoro and 90% in Sikasso regions) reported that poor households are vulnerable to soil degradation. 90% and 81% of respondents in Koulikoro and Sikasso reported that even rich families are vulnerable to soil degradation. According to respondents, the consequences of soil degradation on poor households are: decline in crop production which leads to hunger, the bursting and the impoverishment of the families. But most of them reported that poor households are more vulnerable than rich families. Rich families will face additional expenses but they have enough resources to buy fertilizers, animals and agricultural equipments such as plough and drill. They have enough resources to buy food, medicines and can even send their children to school.

Figure 27 Vulnerability of Poor Families due to Soil Degradation

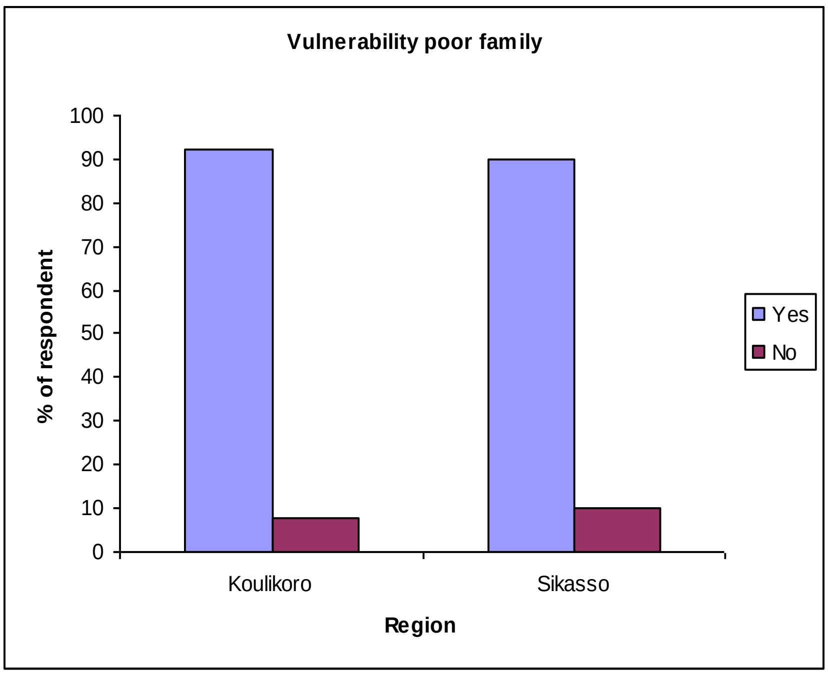
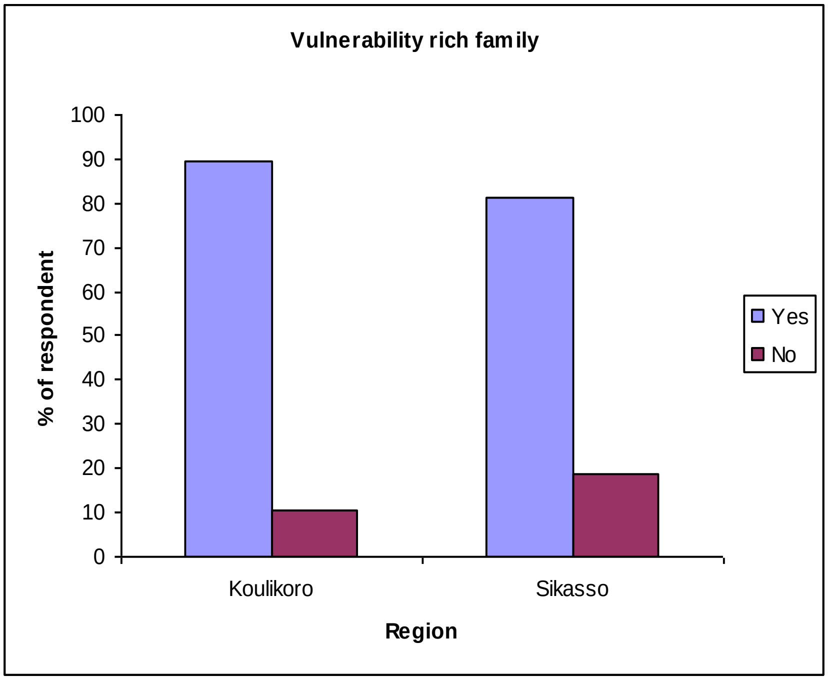


Figure 28 Vulnerability of Rich Families due to Soil Degradation



Soil Fertility Improvement Techniques

In response to the question on knowing soil fertility improvement techniques, 97% of the respondents reported that they know about some soil fertility improvement techniques. Only 3% reported that they don't know any soil fertility improvement techniques.

Among soil improvement techniques, organic manure, mineral fertilizer, composting and tree planting were cited by respondents.

- **Organic manure**

In Koulikoro and Sikasso regions, the majority of farmers (77%) know organic manure as soil improvement technique. Organic manure is known by more farmers in Sikasso region (44%) than in Koulikoro with 33 % of the respondents (Figure 29). It appears from Figure 29 that organic manure is most known by many farmers in the circles of Kolokani, Bougouni, Sikasso and Koutiala respectively. Figure 30 shows the knowledge of organic manure in the villages. It appears that the organic manure is well known in Sananko followed by Banabougou and Kouroukanda. Organic manure is used by 51% and 50 % of respondents in Koulikoro and Sikasso regions respectively. It is in Sananko village that the highest percentage of respondents (10%) using organic manure is found.

- **Mineral fertilizer**

Concerning the mineral fertilizer as soil fertility improvement technique, 52% of the respondents knew it while 47% didn't know it. It is surprising that mineral fertilizer is more known by the majority of respondents in Koulikoro region (31%) than in Sikasso where it is known by only 20% as soil fertility improvement technique (Fig.31). Mineral fertilizer is not perceived by most of the farmers in Sikasso and Bougouni as soil improvement technique. The highest percentages of respondents knowing mineral fertilizer as soil fertility improvement technique are found in Banabougou, followed by Sananko, Moribougou, Dani and Kouloukoura (Fig.32). It is also in Debela village that the highest percentage of respondents (10%) using mineral fertilizer is found.

- **Composting technique**

In all the villages surveyed, 72% of the respondents did not know the composting technique while 28% knew it as soil fertility improvement technique.

- **Tree planting**

Only 19% of respondents knew tree planting as soil fertility improvement technique while 80% didn't know it. Tree plantation is perceived more in Sikasso (23%) as soil fertility improvement technique (Fig. 33) than in Koulikoro (14%). Although tree planting is not known as soil fertility improvement technique by the majority of respondents, it is in Koutiala, Bougouni and Sikasso that the highest percentage of farmers knowing it is found. It is in the village Sananko that the highest percentage of respondents knowing tree planting as soil fertility improvement technique is found (Fig. 34). The majority of respondents (96%) in the two regions reported that they do not use tree planting as soil fertility improvement technique. It is also in Sananko that tree planting is used by the highest percentage of respondents (Fig. 35).

Soil fertility improvement techniques such as crop rotation, cereal-legume association, fallowing, parking of animal, crop residues incorporation, ploughing, live fences, parklands, stones rows, controlled natural regeneration were not mentioned by farmers as known techniques.

Figure 29 Knowing Organic Manure as Soil Improvement Technique in Regions

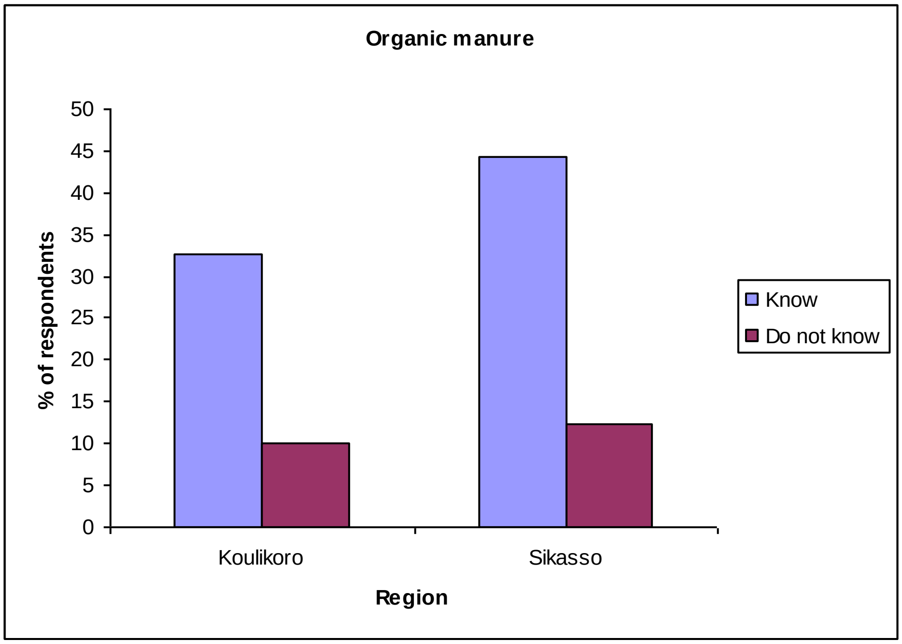


Figure 30 Knowing Organic Manure as Soil Improvement Technique in the Villages

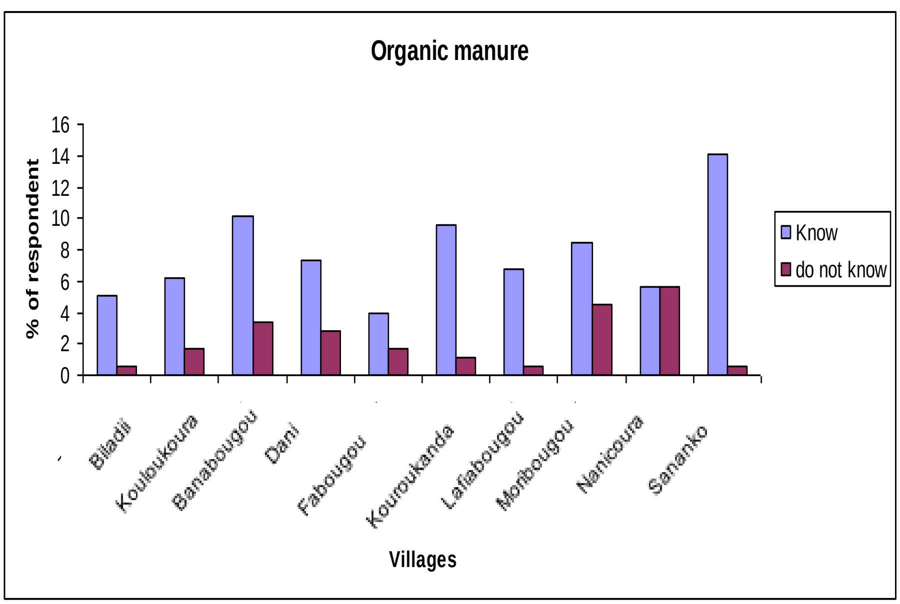


Figure 31 Mineral Fertilizer as Soil Fertility Improvement Technique According to Regions

Figure 32 Mineral Fertilizer as Soil Fetility Improvement Technique at Village Level

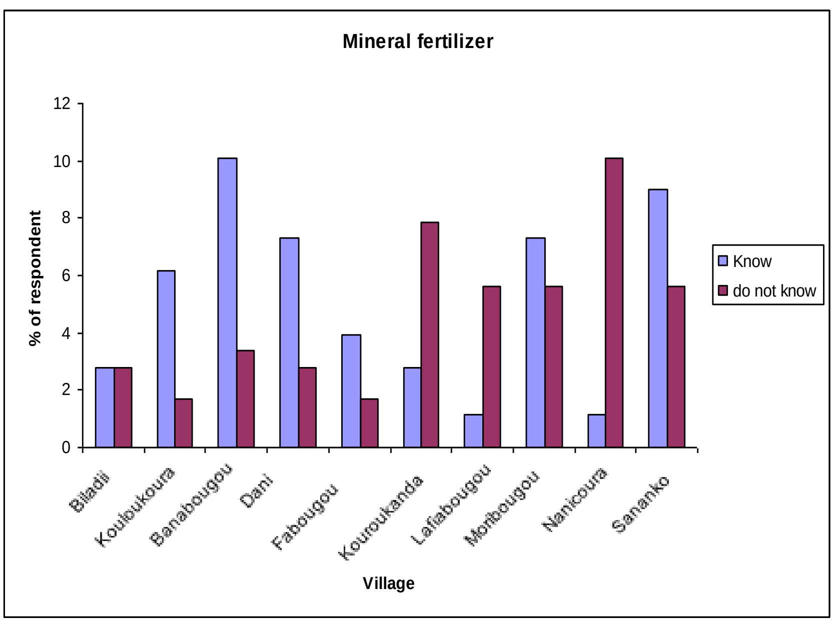


Figure 33 Knowing Tree Plantining as Soil Fertility Improvement Technique in the Regions

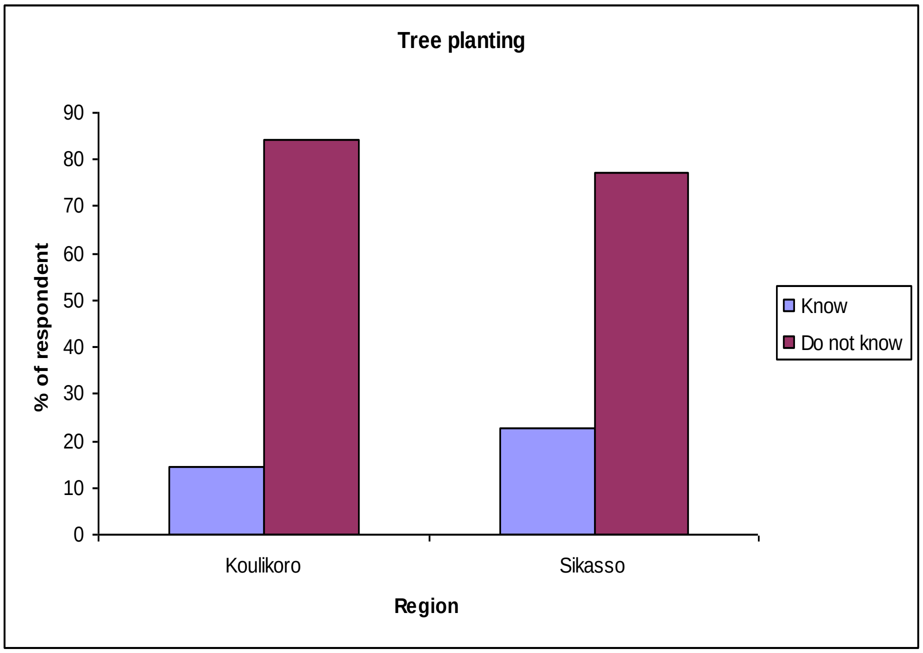


Figure 34 Knowing Tree Planting as Soil Fertility Improvement Technique in the Villages

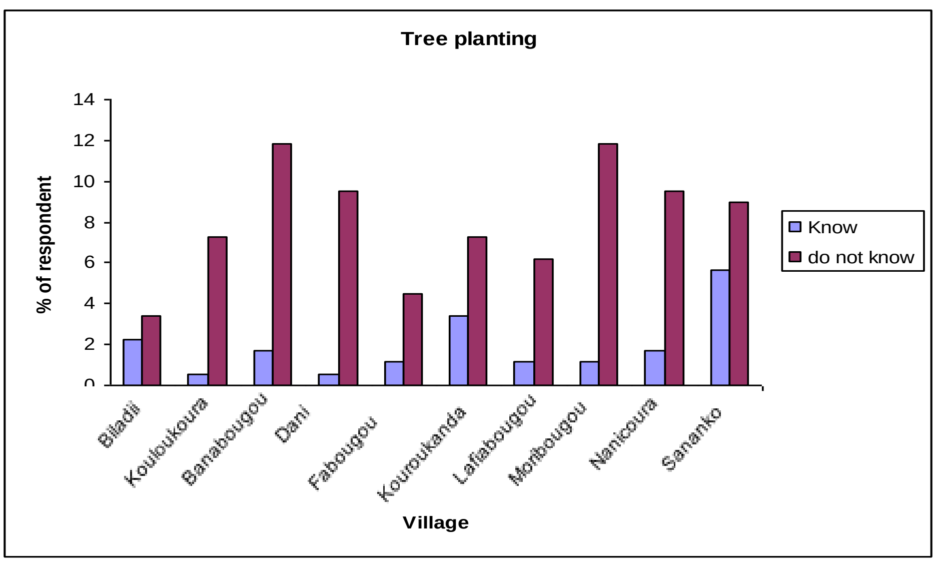
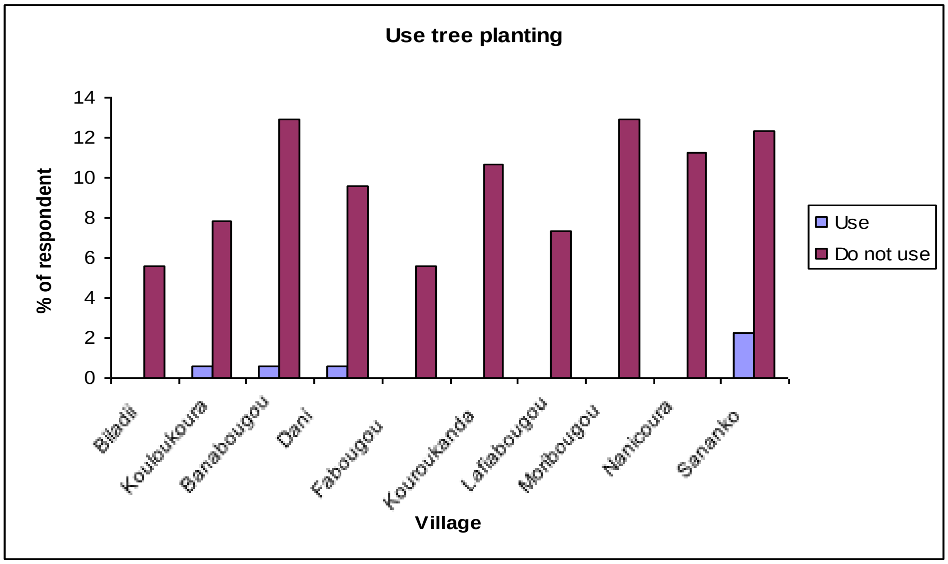


Figure 35 Using Tree Planting as Soul Fertility Improvement Technique in the Villages



Water Availability

- **Wells state**

In response to the question whether wells dries up during the dry season, 90% and 50% of the respondents reported that wells dries up in Koulikoro and Sikasso regions respectively. Figure 36 shows the state of wells in the different villages. It is clear that wells dried up in dry seasons in most of the villages except in Sikasso region in villages such as Sananko, Nanicoura and Moribougou where more than half of the respondents reported that wells do not dry up.

- **Permanent ponds and rivers in village territory**

In response to the question if there are permanent ponds and rivers in their village territory, 99% of the respondents in Koulikoro reported that that there are no permanent rivers and ponds in their region while in Sikasso 52% of respondents reported that there are permanent ponds and rivers in their region. Most of the respondents in the villages reported that there are no permanent rivers and ponds in their villages except villages such as Moribougou and Nanicoura and Lafiabougou in Sikasso region (Fig. 37). A high majority of respondents from different villages (88%) reported that there are temporary ponds and rivers in their village territories.

Assuming that wells did not dry up, in response to the question whether there will be sufficient water in the dry season to irrigate gardens and tree plantation, 47 % and 40% of respondents in Sikasso and Koulikoro regions did not know because they do not give any answer. In Sikasso region, 33% of respondent reported that there is sufficient water in the dry season to irrigate gardens and tree plantation while in Koulikoro 51% reported the contrary. Figure 38 shows that in wells in some villages such as Sananko, Nanicoura, Moribougou and Biladji there is sufficient water to irrigate gardens and trees.

- **Rainfall tendency**

In response to the question on rainfall tendency in the past 5 to 10 years, the majority of respondents reported a decrease in rainfall availability (70% in Koulikoro and 100% in Sikasso region). From figure 39 it appears that most of the respondents in the villages have noticed a decrease in rainfall in the past 5 to 10 years.

- **Impact of rainfall decrease on crop production**

In response to the question of the impact of the decrease of rainfall on crop production, the majority of respondents reported a decrease in crop production (75% in Koulikoro and 88% in Sikasso regions respectively). As shown in figure 40, all respondents reported a decrease in crop production when there is a decrease in rainfall. A high score up to 100% have been reported in villages such as Sananko, Nanicoura, Lafiabougou, Kouroukanda and Biladji.

Figure 36 Wells state in the villages in Sikasso and Koulikoro regions

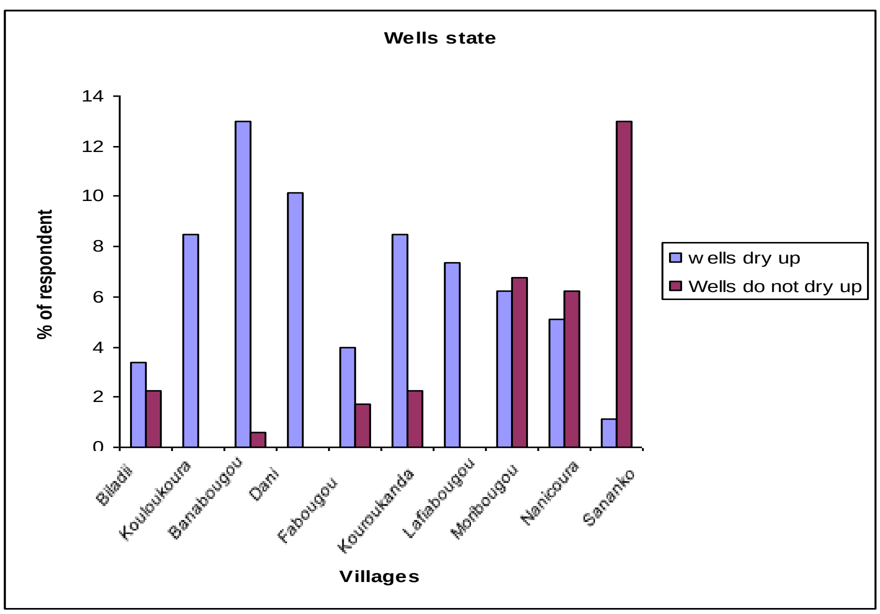


Figure 37 Existence of Permanent Rivers and Ponds in the Villages

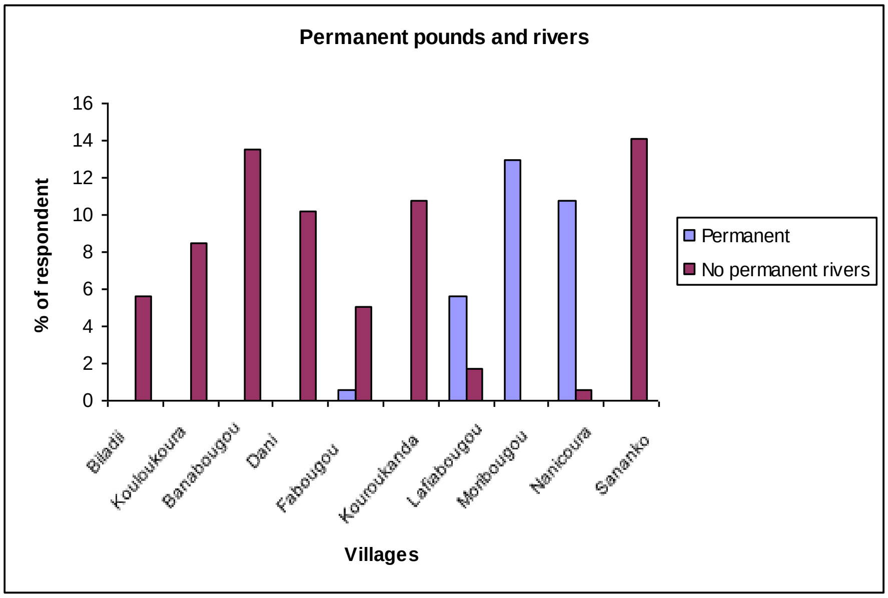


Figure 38: Water Availability to Irrigate Gardens and Tree Plantations

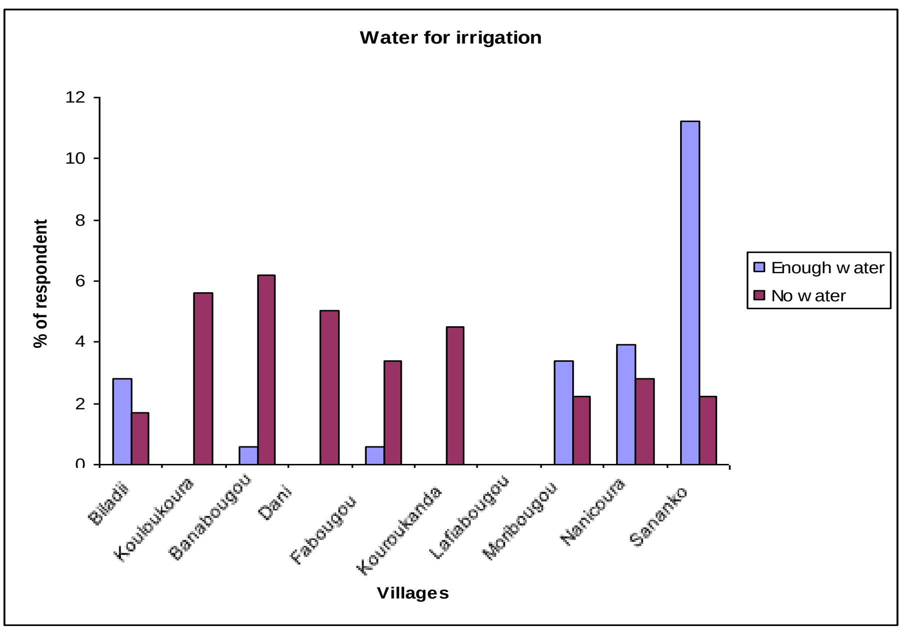


Figure 39: Rainfall Tendency in the Past 5 to 10 Years According to Village

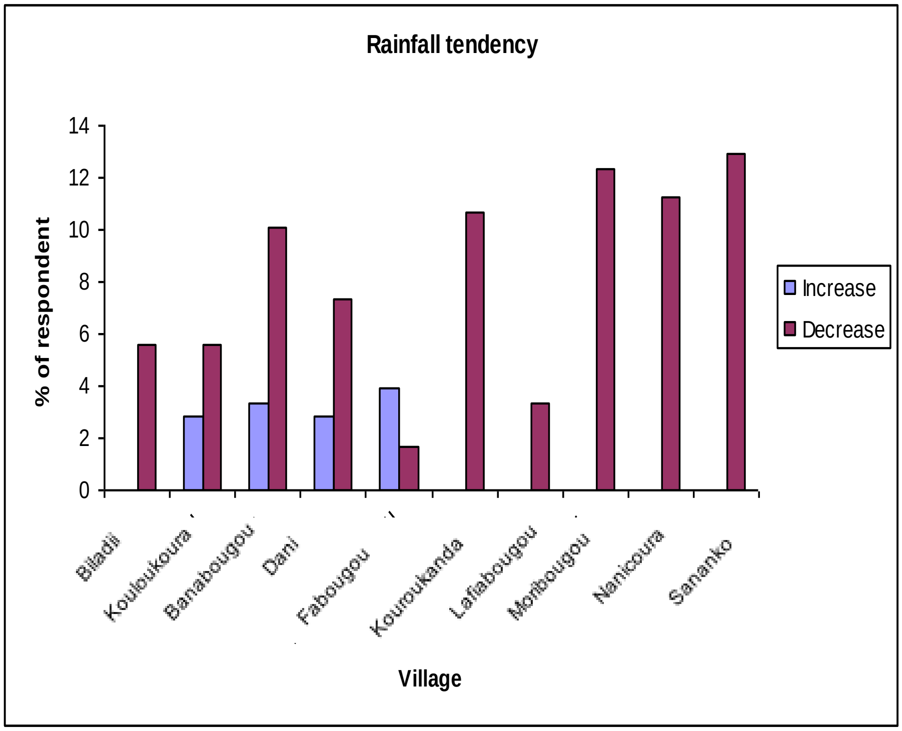
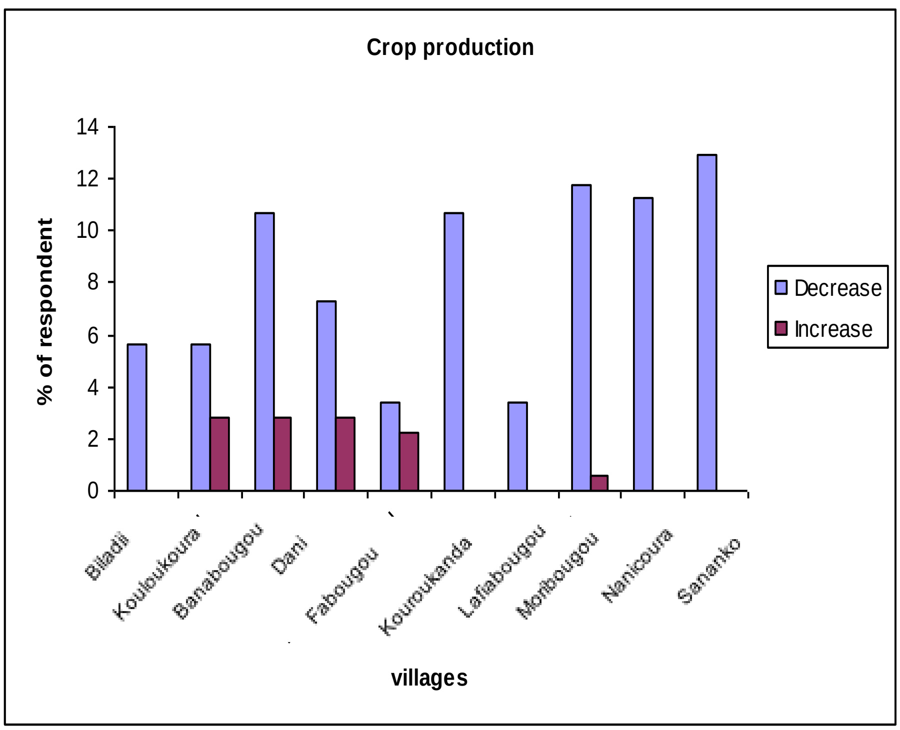


Figure 40: Impact of Rainfall Decrease on Crop Production



Water Conservation Technique

- **Stone rows as water conservation technique**

In response to the question of stone rows as water conservation technique, 88% of the respondents in Koulikoro region knew it while only 48% in Sikasso region knew the technique (Fig. 41). In response to the question whether they use it, the majority of respondents reported that they do not use the technique (99% in Sikasso and 82% in Koulikoro). In comparing villages, it appears from figure 42 that the majority of respondents knew stone rows as water conservation technique except in Nanicoura and Sananko villages where the percentage of people do not knowing it is higher than those knowing the technique.

- **Ploughing as water conservation technique**

Ploughing is known as water conservation technique by 69 and 71% of the respondents in Koulikoro and Sikasso regions respectively (Fig. 43). From figure 44, it appears that most of respondents knew ploughing as water conservation measure in the villages. In response to the question whether they use it, 57% and 47% of the respondents reported that they do not use ploughing as water conservation technique in Sikasso and Koulikoro regions respectively.

- **Tree planting as water conservation technique**

Tree planting is known as water conservation technique by 71 and 53% of the respondents in Sikasso and Koulikoro regions respectively (Fig. 45). Tree planting is well known as water conservation technique in villages such as Sananko, Moribougou, Kouroukanda and Kouloukoura (Fig. 46). In response to the question whether they use it, 92% and 82% of the respondents reported that they do not use tree planting as water conservation technique in Sikasso and Koulikoro regions respectively.

- **The contour line management**

The contour line management technique is not known by 94% and 90% of respondent in Koulikoro and Sikasso regions respectively.

- **Live fence**

Live fence is not known by 62% and 65% of the respondents as water conservation technique in Koulikoro and Sikasso regions respectively.

- **Fallow as water conservation technique**

Fallowing is known by 62% of the respondents in Koulikoro region while in Sikasso, 69% of the respondents did not know the fallows as water conservation technique.

Land enclosure, earth bund and organic manure are not known by the majority of respondents as water conservation techniques in Koulikoro and Sikasso regions.

Figure 41: Stone Rows as Water Conservation Technique in Two Regions

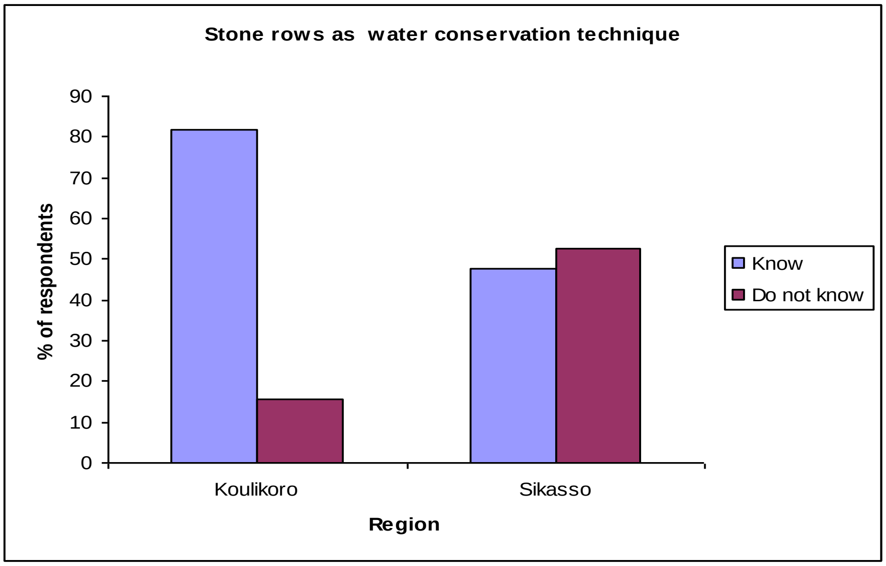


Figure 42: Stone Rows as Water Conservation According to Villages

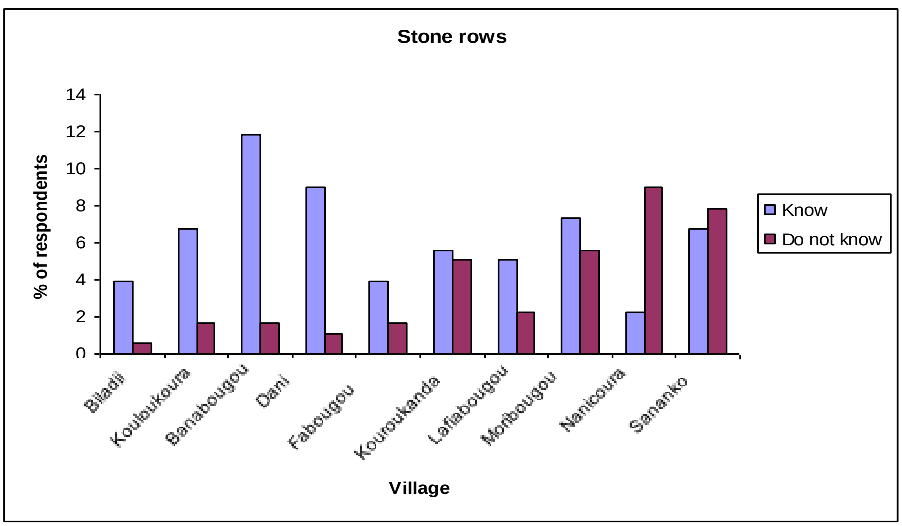


Figure 43: Ploughing as Water Conservation Technique in the Two Regions

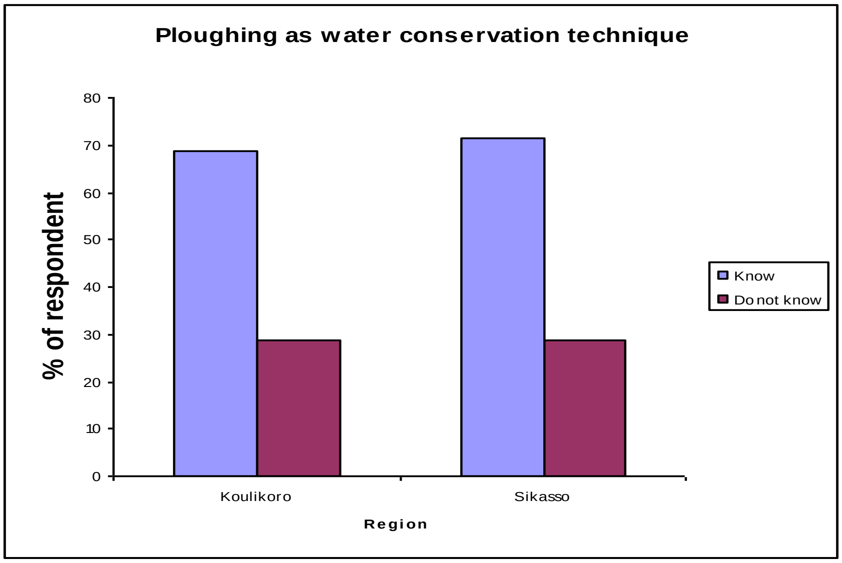


Figure 44: Ploughing as Water Conservation Technique According to Villages

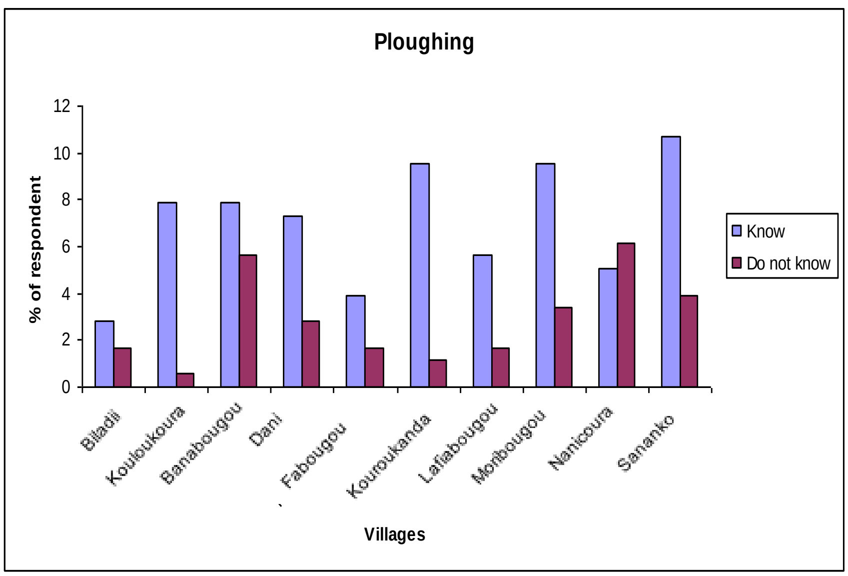


Figure 45: Tree Planting as Water Conservation Technique in the Two Regions

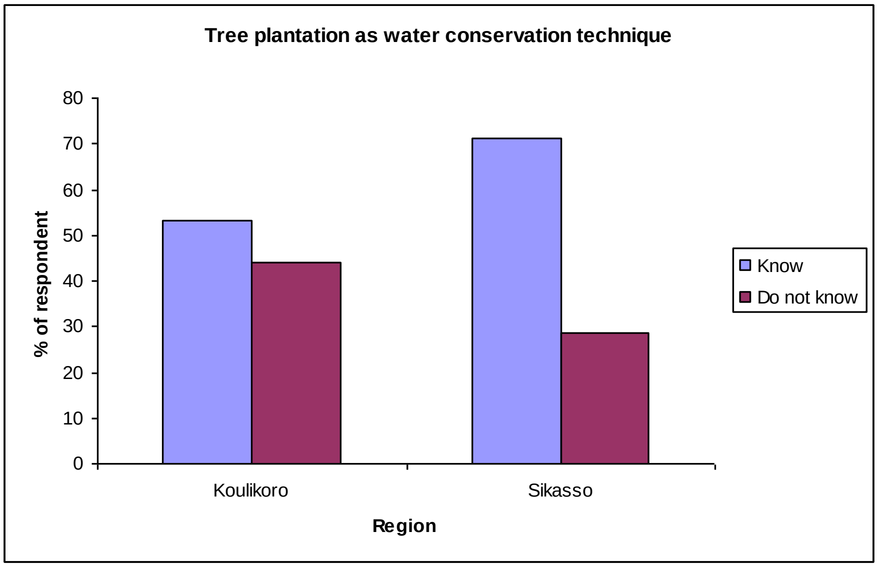
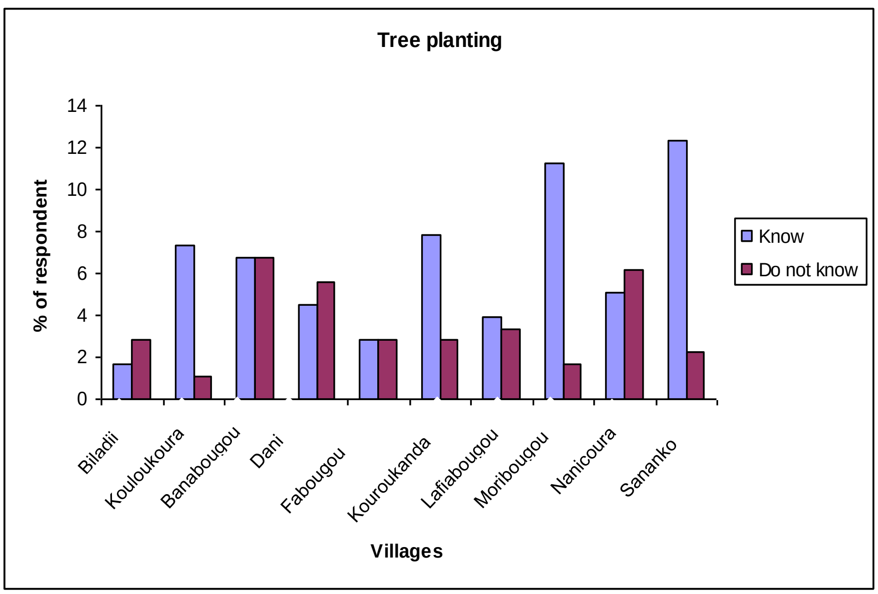


Figure 46: Tree Planting as Water Conservation Technique in the Villages



Discussion

Soil Fertility State in Koulikoro and Sikasso Regions

Concerning the soil fertility status, a high majority of the respondents are aware that the soils are not fertile and there is a decline in soil fertility in the past 5, 10 and 20 years. Overexploitation and soil erosion of fields are perceived respectively as the main causes of soil fertility decline. The lack of resources was mentioned by some respondents. All the respondents agreed that there will be a decrease in crop production when soil fertility declines. It is also obvious to most of the respondents that poorer soils are being degraded faster than richer soils. A high majority of farmers (90% in Koulikoro and Sikasso regions) reported that both poor and rich households are vulnerable to soil degradation. But most of them reported that poor households are more vulnerable than rich families.

Soil Fertility Improvement Techniques in Koulikoro and Sikasso Regions

Among soil improvement techniques known by farmers, organic manure, mineral fertilizer, composting and tree planting were cited by respondents.

The majority of farmers (77%) know organic manure as soil improvement technique. Organic manure is used by 51% and 50 % of respondents in Koulikoro and Sikasso regions respectively. It is in Sananko village that the highest percentage of respondents (10%) using organic manure is found. 52% of the respondents knew mineral fertilizer as soil fertility improvement technique. It is also in Sananko village that the highest percentage of respondents (10%) using mineral fertilizer is found. Only 19% of respondents knew tree planting as soil fertility improvement technique. It is also in Sananko that tree planting is used by the highest percentage of respondents.

Water Availability in Koulikoro and Sikasso Regions

It is clear that wells dried up in dry seasons in most of the villages except in Sikasso region in the villages Sananko, Nanicoura and Moribougou where more than half of the respondents reported that well do not dry up. There are no permanent rivers and ponds in Koulikoro region as reported by respondents. In Sikasso regions permanent rivers or ponds can be found in villages such as Moribougou and Nanicoura and Lafiabougou. The majority of respondents reported a decrease in rainfall availability (70% in Koulikoro and 100% in Sikasso region) in the past 5 to 10 years. The majority of respondents reported a decrease in crop production (75% in Koulikoro and 88% in Sikasso regions respectively) when rainfall decreases.

Water Conservation Techniques in Koulikoro and Sikasso Regions

- **Stone rows as water conservation technique**

  Stone rows are known as water conservation technique as reported by the majority of respondents but they do not use the technique (99% in Sikasso and 82% in Koulikoro).

- **Ploughing as water conservation technique**

Ploughing is known as water conservation technique by 69 and 71% of the respondents in Koulikoro and Sikasso regions respectively. In contrast to the other techniques ploughing is used by nearly half of the population.

- **Tree planting as water conservation technique**

Tree planting is known as water conservation technique by 71 and 53% of the respondents in Sikasso and Koulikoro regions respectively. Tree planting is well known as water conservation technique in villages such as Sananko, Moribougou, Kouroukanda and Kouloukoura. But most of the respondents do not use tree planting as water conservation technique.

Live fence, land enclosure, earth bund and organic manure are not known by the majority of respondents as water conservation techniques in Koulikoro and Sikasso regions.

Perceptions of Technical and Scientist Resource Persons on Soild Fertility and Water Availability

In the present study of Oxfam America, a survey was conducted in Bamako district, Koulikoro and Sikasso regions to illicit technical and scientist resource persons knowledge and practices concerning soil fertility and water availability changes over the past 5, 10, 20 years.

Material and Methods

Resource persons from research institutes, non-governmental organisations and state technical services were interviewed. Structured and semi-structured interview were used during the survey. An additional questionnaire was also given to each resource person to fill in. Questions were asked about the following topics:

- Current state of soil fertility in Sikasso and Koulikoro regions;
- Current state of the availability of agricultural water via irrigation, groundwater, or rain;
- Scientifically founded predictions for the future state of soil fertility and water availability in Mali in the next 5, 10, 20 years;
- Areas of better water availability or better soil fertility;
  Soil fertility improvement techniques (including low-cost techniques and their adoptability);
- Water availability improvement techniques (including low-cost techniques and their adoptability).

The sample questionnaire and the list of resource persons interviewed are presented in annexes 3 and 4.

Results

- **Current State of Soil Fertility in Sikasso and Koulikoro Regions**

Technical services agents, research institutions and non-governmental organizations are unanimous on the fertility degradation in the Koulikoro and Sikasso regions (circles of Sikasso, Bougouni, Koulikoro, Koutiala, Banamba, Kati and Kolokani). However, some believe that the geomorphology plays an important role: Fertility is generally high in the lower glacis while there are problems of soil fertility degradation on top and slopes of the toposequence.

In these areas the fertility decline has been observed during the past 5, 10 and 20 years depending on the location.

The causes of soil fertility decline mentioned by the respondents are: overexploitation, erosion, climate change (drought), migration of animals (pasture) from the north to the south, clearing and excessive cutting of wood for fire wood and charcoal production and the non-adoption of erosion control techniques.

One reason cited in Koutiala is the human pressure due to the cultivation of cash crops especially the cotton boom of the years 1990. Cotton cultivation is practiced extensively, the cultivated areas are increasing at the expense of forest cover and there is no appropriate management towards intensification.

According to an official of the CMDT Koutiala, the average age of the field is 20 years and ploughing is done every year (overexploitation). There are in the Koutiala zone over 70 000 farms and 80% of these farmers have agricultural equipments. All farmers are becoming also breeders because they invest the money earn from cotton cultivation to buy animals. As a result animal pressure on land is increasing. There are hardly fallows lands in Koutiala and Sikasso areas.

It would be desirable to undertake prospective studies to make predictions about the state of soil fertility in these regions (NGOs AMEDD and GRAADECOM).

- **Current State of the Availability of Agricultural Water via Irrigation, Groundwater or Rain**

A decrease in rainfall during the past 5, 10 and 20 years was reported by the majority of respondents. Agricultural activity is exclusively dependent on rainfall in Koulikoro and Sikasso regions. Rain water availability fluctuates within and between years. The rainy season is characterized by difficult beginnings and ends. In the middle of the rainy season, there are torrential rains that degrade the soil (erosion). There are irrigable lowlands in Bougouni and Sikasso zones.

Kénédougou basin (Lotio River) can irrigate one million hectares when the depression areas are very well managed. Dams improve the supply of ground water, then construction of small dams and large-diameter wells can improve the availability of water for agriculture since the plains remain wet until some time in the dry season. In lowlands in Koulikoro and Sikasso regions, ground water is used for gardening during the dry season. All the respondents are aware about the lack of runoff control and water conservation technique in the study areas

Rainwater harvesting was reported as a very reliable option to be developed in Koulikoro and Sikasso regions by some of the respondents.

- **Scientifically Founded Predictions for the Future State of Soil Fertility and Water Availability in Mali in the next 5, 10, 20 Years**

The National Agricultural Policy Plan and the Guide of Agricultural Law were elaborated by the Ministry of Agriculture in Mali, but these plans did not get material and financial support from the state. However an agent of the agricultural service in Koulikoro reported that future predictions indicate an increase in fertility (organic manure use) due to the presence of more and more tractors. 40 truckloads of organic manure applied to 1 ha of maize give a good yield.

A hydrology report for Mali can be found at the National Water Headquarter in Bamako. There is a national plan for improving water management in the next 10 years in a document called "Integrated Water Resources Management (GIRE) in Mali.

- **Areas of Better Water Availability or Better Soil Fertility**

According to many respondents, all areas near rivers are good for agriculture. Pre- Guinean and Sudanian zones have still better water availability or better soil fertility (great potential) than arid areas (Sahel and Sahara). Lowlands are more fertile with better water availability due to the proximity of the water. In lowlands, Shea butter tree parklands are areas with better moisture and more organic matter. In Bougouni circle, the lowlands in the areas of Sido, Chantoula and Keleya have better water availability and better soil fertility. A project on the integrated management of Lotio River was financed by a Danish Agency in order to supply drinking water to the city of Sikasso. Soil fertility is high in the area of Kadiolo, Southern Sikasso and Finkolo (Guanadougou). According to a respondent there is no exceptional area of fertility in Kolokani, but the availability of water is better in the area of Ouaya Lake, South and West of the Baoulé National Park. In the area of Sirakorola (Koulikoro), there is an irrigable area in Zana village due to the existence of a river flowing from Koula to N'guabakoro. In Koulikoro circle, the plain of Dianikoro and large lowlands from Dogoni up to Dokala have better water availability and better soil fertility.

In conclusion we can notice that there are still in the two regions, areas of better water availability or better soil fertility but efficient use and sustainable management of available soil and water resources are lacking.

Women, poor families and migrants are more vulnerable to the changes in soil fertility and water availability due to the fact they do not have money to buy fertilizer or do not have a cart to transport organic manure or even do not have land for farming.

- **Soil Fertility Improvement Techniques**

The techniques for improving soil fertility identified by the respondents are: stone rows, tillage, ridge, contour line, live fences (hedgerow), enclosure, composting, organic manure, grass strips, planting trees such as *Gliricidia sepium*, *Piliostigma reticulatum* (Niama) and *Faidherbia albida* (Balazan), fallowing, crop rotation, earth bund, tillage at the end of agricultural cycle, improved clearing, assisted natural regeneration (RNA), liming, green manure, the abandonment of the use of herbicides and agroforestry parklands (Balazan, *Vitellaria paradoxa* (Karité).

Tillage, tree planting, organic manure, assisted natural regeneration, fallow, contour line, green manure, grass strips and earth bunds are the low-cost techniques that can be spread through education.

According to participant's experiences, techniques such as organic manure, ridge, earth bund, green manure and crop rotation did work and techniques such as stone rows, contour rows, hedge and tillage at the end of cycle did not work.

The main causes of non-adoption of the techniques by farmers cited by respondents in order of importance are:

- Lack of resources;
- Lack of know how;
- Poor extension of the techniques;
- Inappropriate government policies;
- Lack of incentives;
- Lack of seed supply for tree and grass plantation;
- Inadequate involvement of farmers at the beginning of projects and
- Lack of interest.

Bayala (2012) reported that if farmers do not see immediate tangible benefits, they are less likely to adopt a technology. Short term benefits are important because they determine to a large extent the attractiveness of a technology to farmers (Giller et al., 2009).

The NGO's or organizations that can undertake the work are: TONUS and CAEB in Koulikoro region, IFDC, GRAADECOM, AMAPE, GIE Coulibaly and Caritas Mali in Sikasso, AMEDD and CMDT in Koutiala, CAEB in Bougouni.

- **Water Availability Improvement Techniques**

Field contour with clay, Rehabilitation of large diameter wells, drilling, small dams, rainwater harvesting technology, stone rows, grass strips, earth bunds, tree planting, assisted natural regeneration, lowlands water management, pastoral ponds management and contour lines have been identified as techniques to improve water availability for agricultural activities

Tree planting [Gliricidia sepium, Tephrosia voguelii and Piliostigma reticulatum (Niama)], composting, assisted natural regeneration and hedgerows have been cited as low-cost techniques that can be spread through education.

Most of the respondents reported that all the techniques used are not the same as those used in the agriculture pilot.

The main causes for the non- adoptions of water conservation technique and soil fertility improvement are the same.

The necessary expertise and supplies for using these techniques can be found in the following organizations:

- Technical services of agriculture, hydraulic and forestry;
- NGOs (Tonus, CAEB, GRAADECOM, AMEDD, Oxfam-America);
- CMDT (Compagnie Malienne de Développement du textile);
- IER (Institut d'Economie Rurale).

CHAPTER 6

GENERAL CONCLUSION

Soil Fetility and Water Availability States in West Africa and Mali

The results of this review indicated that soil fertility and water availability are major problems in West Africa in general and particularly in Mali. According to Zougmoré et al. (2010), land degradation is a major constraint to the sustainability of agricultural systems in semi-arid areas of West Africa. Some of the causes of soil degradation include the shortening of the fallow period, the degradation of parklands, the conversion of forest cover to agriculture (expansion of cultivated areas) and also most African soils are fragile, inherently very low in organic carbon, nitrogen and phosphorus. Factors such as agro technical changes, socio-economic changes, the migration of livestock southward, institutional and legislative reforms of agricultural sector have worsened the soil fertility problems in Sahelian countries of West Africa.

In order to improve and maintain soil fertility, many strategies (from 1960 to 2013) have been developed by the governments of Mali and some have been implemented. These strategies included the sectoral approach, the national plan for integrated soil fertility management, the sustainable land management (SLM), the microdose fertilization, the rice initiative and the soil fertility map of Mali.

Sahelian countries are characterized by a tropical climate with a single rainy season lasting 2-4 months (Sissoko, 1998). Rainfall varies between 100 and 1100 mm per year. Rainfall is characterized by a high variability: total annual rainfall, starting date of the season, duration and distribution during the rainy season. Water erosion is a serious threat to the sustainability of agricultural land use and it affects soil productivity (Laflen and Roose, 1998; Zougmoré et al. 2010). Water erosion is responsible for the negative nutrients and carbon balances in most farming systems in West Africa (Zougmoré et al. 2010) and for the reduction of crop rooting depth (Morgan, 1995). Rainwater constitutes the main water resources of Sahelian countries and provides in average 415 billion m^3 of water per year in Mali. This drought becomes more pronounced due to the reduction of the mean annual rainfall. The inhabitants suffer most from rainfall uncertainty and drought. A comparison between the years 1950s and 2000s reveals downward trend of isohyets from North to South.

The hydrographic system of Mali is mainly composed of three basins: The Niger, Senegal and Volta basins. Problems of degradation of water resources in Mali included domestic pollution, degradation and illegal occupation of river banks, industrial and traditional pollution, deforestation, silting and the pollution related to agricultural activities.

Available Soil and Water Conservation Technologies

According to Bationo et al. (1996), these different technologies can be grouped into techniques such as: 1) Soil protection and water conservation; 2) Improvement of land use systems and 3) Adding mineral and organic fertilizers.

Soil protection and water conservation techniques found in the literature included stones rows, mulching, ridging (Ploughing), zaï, half-moons and the contour line management technique.

Improving the land use system refers to hedges (living fences), grass strips, forage sole or improved fallows, assisted natural regeneration (ANR) and crop rotation (association cereals - legumes).

Measures of crop fertilization included crop mineral and organic fertilization. Crop mineral fertilization is based on adding fertilizers such as nitrogen, phosphorus, potassium and trace elements like zinc, boron and sulfur while organic fertilization concerned improved animal parks and incorporation of crop residues and green manure.

Gliricidua Experimental Plots

The results of the soil analysis showed that the soils have coarse (sandy loam) texture, light and easy to work. Soils are potentially acidic ($\Delta pH > 1$), relatively poor in organic matter and nutrients (especially nitrogen and phosphorus). Therefore it is necessary to properly apply organic and mineral fertilizers as advised by extension services.

The high survival rate and the healthy state of trees indicated that *Gliricidia sepium* plantation was a success in most of the pilot villages.

Farmers' Base Line Survey

Soil Fertility

The results of interviews indicated that a high majority of respondents reported that they have soil fertility problems since there is a decline of soil fertility over the past 5, 10 20 and years.

Overexploitation of fields, soil erosion and lack of resources are perceived respectively as the main cause of soil fertility decline in Sikasso and Koulikoro regions. Among soil improvement techniques, organic manure, mineral fertilizer, composting and tree planting were cited by respondents. The best known and used soil fertility improvement technique is organic manure followed by mineral fertilizer, composting and tree planting respectively.

Water Availiability

The majority of respondents reported a decrease in rainfall availability (70% in Koulikoro and 100% in Sikasso region). With regards to water availability, it appeared that there is more water in Sikasso region than Koulikoro. In Koulikoro region, the majority of respondents reported that wells dries up and that there are no permanent ponds and rivers while in Sikasso, more than half of the respondent claimed that some wells do not dry up and there some permanent rivers and that there is sufficient water in the dry season to irrigate gardens and tree plantation. Among the water conservation technique, the best known in order of importance are ploughing, stone rows, tree planting and fallowing. The most used techniques are ploughing and stone rows.

Perceptions of Technical and Scientist Resource Persons on Soil Fertility and Water Availability

Technical services agents, researchers and non-governmental organizations agents are unanimous on the fertility degradation in the Koulikoro and Sikasso regions. The causes of soil fertility decline mentioned by the respondents are: overexploitation, erosion, climate change (drought), migration of animals (pasture) from the north to the south, clearing and excessive cutting of wood for fire wood and charcoal production and the non-adoption of erosion control techniques.

A decline in rainfall during the past 5, 10 and 20 years was reported by the majority of respondents which resulted in a decrease of crop yields. The causes of water availability decline reported are: rainfall decline, climate change (risk of drought) and lack of forest cover.

The low-cost soil improvement techniques identified that can be spread through education are: tillage, tree planting, organic manure, assisted natural regeneration, fallow, contour line, green manure, grass strips and earth bunds.

The low-cost water conservation techniques are: tree planting, composting, assisted natural regeneration and hedgerows.

In conclusion, it appears that farmers are aware about soil fertility and water availability declines. Farmers know many soil improvement and water conservation techniques but in most of the cases they don’t use them. There is a need to understand why the adoption of improved technologies is low. Moreover, it is obvious that the current data on improved soil fertility and water conservation are sparse. Research is needed to understand them, their interactions, their specific context and their adoptability.

REFERENCES

Allen, M. Diakité, M., Gana, I. 2009. Regreening the Sahel: A case study of farmer managed natural regeneration in Mali. Sahel Eco, Bamako, Mali, 21 p.

Amoukou, A.I., M. Ali, A. Awaïss, I. Soumana & M. Djerralar, 1996. Stratégiespaysannes après la sécheresse de 1973, cas du village de Goumza au Niger. Centre National d'Etudes Agronomiques des Régions Chaudes (CNEARC), p 95-99.

Aune, J. B., Doumbia, M., and Berthe, A. 2007. Micro fertilizing sorghum and pearl millet in Mali: agronomic, economic and social feasibility. Outlook on Agriculture. 36:199-203.

Bagayoko, M., Mason, S.C., Traoré, S. Eskridge, K.M. 1996. Pearl milley/cowpea cropping systems yield and soil nutrient levels. African Crop Science Journal 4: 453-462.

Bationo, A., Hartemink, A., Lungu, O., Naimi, M., Okoth, P., Smaling, E.,Thiombiano, L. 2006. African Soils: Their Productivity and Profitability of Fertilizer Use. Background Paper Presented for the African Fertilizer Summit9-13th June 2006. Abuja, Nigeria.

Bationo, B.A., Yélémou, B., Ouédrago, S.J. 2004. Le neem (Azadirachta indica), une espèce exotique adoptée par les paysans du centre-ouest du Burkina Faso. Bois et forêts des tropiques 282 : 5-10.

Bationo, A., Traoré, Z., Kimetu, J., Bagayoko, M., Kihara, J., Bado, V., Lompo, M., Tabo, R., Koala, S. 2003. Cropping Systems in the Sudano-Sahelian Zone: Implications on Soil Fertility Management From: http://www.syngentafoundation.org/db/1/432.pdf.

Bationo, A., F. Lompo & S. Koala, 1998a. Research on nutrient flows and balances in west Africa: State-of-the art. Agriculture, Ecosystems & Environment 71: 19-35.

Bationo, A., E. Rhodes, E.M.A. Smaling & C. Visker, 1996. Technologies for restoring soil fertility. In: A.U. Mokwunye, A. de Jager & E.M.A. Smaling. Restoring and maintaining the productivity of West African soils: key to sustainable development., IFDC-Africa, LEI-DLO, SC-DLO. p 61-82.

Bationo, A., A. Buerkert, M.P. Sedogo, B.C. Christianson & A.U. Mokwunye, 1993. A critical review of crop-residue use as soil amendment in the West African semi–arid tropics. Proceedings of an International Conference, International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia, 22-26 November 1993, Volume II, p 305-322.

Bayala, J., Kalinganire, A., Tchoundjeu, Z., Sinclair, F., Garrity, D. 2011. Conservation agriculture with trees in the West African Sahel – a review. ICRAF Occasional Paper No. 14. World Agroforestry Centre, Nairobi.

Bayala, J., Sileshi, G.W., Coe, R., Kalinganire, A., Tchoundjeu, Z., Sinclair, F., Garrity, D. 2012. Cereal yield response to conservation agriculture practices in drylands of West Africa: A quantitative synthesis. Journal of Arid Environments 78, 13-25.

Bitchibaly, K. & L. Dioni, 1992. Zonage agro-climatique, Mali sud. Section de recherche sur les cultures vivrières et oléagineuses (SRCVO), IER, 7 p.

Bosma, R.H., M. Bos, S. Kanté, D. Kébé & W. Quak, 1999. The promising impact of ley introduction and herd expansion on soil organic matter content in southern Mali. Agricultural Systems 62: 1-15.

Bosma, R. & B. Jager, 1992. Le fumier, production dans les parcs et valeur. Etude bibliographique. Rapport de recherche, 25 p.

Breman, H., Groot, J.J.R., van Keulen, H. 2001. Resource limitations in Sahelian Agriculture. Global Environment Change, 11: 59-68.

Breman, H., 1998. Soil fertility improvement in Africa. A tool for or a by-product of sustainable production? African Fertilizer Market, special issue on soil fertility, 11: 2-10.

Brons, J., Zaal, F. Kersbergen, L., Ruben, R. 2004. livehood strategies and development pathways at household and village level. The impact of climate change on dry lands: with a focus on West Africa. Environment and Policies Series, 267-291.

Buerkert, A., Piepho, H.P., Bationo, A. 2002. Multi-site time-trend analysis of soil fertility management effects on crop production in sub-Saharan West Africa. Exp. Agric. 38:163–183.

Camara, B. 2011. Dialogue sur les forêts de l’Afrique de l’Ouest. TCP/RAF/3306. 35 p.

Camara, O.S., 1996. Utilisation des résidus de récolte et du fumier dans le Cercle de Koutiala: Bilan des éléments nutritifs et analyse économique. Rapports PSS No 18, Wageningen, AB-DLO, 120 p.

Charpentier, H., L. Ségui & R. Michellon, 1991. Cultures associées, couvertures végétales mortes et vivantes. In: Savanes d'Afrique terres fertiles? Actes des rencontres internationales, Montpellier, France, 10-14 décembre 1990. Ministère de la Coopération et du Développement, Centre de coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), p 333-355.

CMDT, Suivi Evaluation, 1999. Annuaire statistique 98/99. Résultats de l’enquête agricole permanente, 19 p.

CMDT, 2000. Expérience de maintien du potentiel productif en zone CMDT, 22 p.

Coulibaly, A., Fomba, A., Doumbia, M., AUNE, J. B. 2010. Introduction d'une technique de mécanisation de placement simultané de l'engrais de fond et de la semence des cultures mil, sorgho, et maïs. Rapport Final. IER. 23 p.

Coulibaly, I. 2007. It is necessary to invest in farmers' political and mobilization capacities. Africa can feed itself; Nærstad, A. (edt); Can Africa can feed itself conference Oslo, Norway. pp. 26-33.

CPM (Cabinet du Premier Ministre). 2008. Plan d'opération riz. Campagne 2008/2009. Cabinet du Premier Ministre. 28 p.

Delville, P.L., 1996. Gérer la fertilité des terres dans les pays du Sahel. Diagnostic et conseil aux paysans. Collection "le point sur", GRET, 397 p.

Diarra, A. 2006. Rapport sur l'état des lieux des ressources en eau et de leur cadre de gestion Au Mali. Unité de coordination des ressources en eau de la CEDEAO.

Dicko, M.S., Gjitèye, M.A., Sangaré, M. 2006. Les systèmes de productions animales au Sahel. Sécheresse 17 (1-2), 83-97.

DNEF.2010. Rapport annuel sur les feux de brousse, Bamako

Doumbia, M., GOTO, Y. and TOBA, N. 2007. Place de la gestion durable des terres au Mali. Etude réalisée dans le cadre de TerrAfrica et financée par la Banque Mondiale. Ministère de l'Environnement et de l'Assainissement. Bamako. 115 p.

Doumbia, A. 2000. Identification des espèces agroforestières pour la production d'engrais vert dans le cadre d'une technologie de transfert de biomasse en système périurbain. Mémoire de fin d'étude d'Ingénieur de L'Institut Polytechnique Rural de Formation et de Recherche Appliqué IPR/IFRA de Katibougou, Mali, 31p.

Dregne, H.E.1990. Erosion and soil productivity in Africa. J. Soil Water Conser., 45 : 431-436.

Dugué, P., 1993. La gestion de la fertilité et l'utilisation des ressources naturelles dans les systèmes agro-pastoraux soudano-sahéliens. Quelques éléments de réflexion à partir des situations du Yatenga (Burkina Faso) et du Sine Saloum (Sénégal). Communication présentée à la journée AGER "Gestion de la fertilité" du 20 janvier 1993. CIRAD-SAR No 26/93, 15 p.

FAO. 2003. Forestry Outlook Study for Africa – African Forests: A view to 2020, Food and Agricultural Organization of United Nations, Rome, Italy.

FAO. 2000. Forest Resource Assessment. FAO Rome

Faye, M.D., Weber, J.C., Mounkoro, B., Dakouo, J.M. 2010. Contribution of parkland trees to village livehoods- A case study from Mali. Development in practice 20: 428-434.

Gakou, A., D. Kébé & B. Traoré, 1996. Gestion de la fertilité des sols au Mali. Esquise de plan d'action. Etude commandée par la Banque Mondiale, 124 p.

Gerner, H. & G. Harris, 1993. Utilisation et approvisionnement des engrais en Afrique sub saharienne. In: H. van Reuler & W.H. Prins. Rôle de la fertilisation pour assurer une production durable des cultures vivrières en Afrique sub-saharienne. VKP, p 119-140.

Gigou, J., Traoré, K., Giraudy, F., Coulibaly, H., Sogoba, B., Doumbia, M.2006. Aménagement paysan des terres et réduction du ruissellement dans les savanes africaines. Cahiers Agricultures. 15:1-6.

Gigou, J. & K. Traoré, 1995. Compte rendu de mission pour visite des tests de courbes de niveau. Programme Régional pour l'Afrique de l'Ouest et du Centre, programme conjoint sorgho, ICRISAT -CIRAD, 10 p.

Giraudy, F & S. Samaké, 1995. La production et l'utilisation de la fumure organique par les exploitations de la zone Mali-Sud. Suivi-évaluation CMDT, 10 p.

Goita, M., Sidibé, M. 2009. Bilan de la recherche agricole au Mali 1970-2000. Centre Nationale de Recherche Agricole, Ministère de l'Agriculture, Bamako, Mali. Volumes 1 et 2.

Guichard, F., Frappart, F., Hiernaux, P., Kergoat, L., Mougin, E., Arjounin, M., Koité, M.,Lebel, T., Bock, O., Meynadier, R., 2010. A multi-scale analysis of in-situ precipitation data across the Sahelian Gourma. Geophysical Research Abstracts 12 EGU 2010-9271-2.

Heuperman, A. F. and Kapoor,A. S.2002. Biodrainage: Principal Experiences and Applications, IPTRID, FAO, Rome, pp. 1–79.

Hiernaux, P., T.O. Williams, S. Fernandez-Rivera & E. Schlecht, 1998. Les rôles de l'élevage dans l'intensification des modes de production agricole au Sahel: Options socio-économiques et techniques. In: H. Breman & K. Sissoko (eds). L'intensification agricole au Sahel. p 686 708.

Hijkoop, J., P. van der Poel & B. Kaya, 1991. Une lutte de longue haleine. Aménagement anti-érosifs et gestion de terroir. Système de Production Rurale au Mali: volume 2. IER/KIT, Mali/Pays Bas, 154 p.

Hoefsloot, B., F. van der Pol & L. Roelveld, 1993. Jachères améliorées. Options pour le développement des systèmes de production en Afrique de l'Ouest. KIT Bulletin No 333. Amsterdam, The Netherlands, 86 p.

ICRISAT. 2004. Micro dose d'engrais pour la prospérité des petits paysans du Sahel. SA Trends Issue 48. http://www.icrisat.org/web/ASP/satrends.asp#2

Kanté, S., 2001. La gestion de la fertilité des sols par classe d'exploitation au Mali-Sud.Tropical Resource Management Papers, 38. Wageningen University.

Kass D. L., Foletti C., Szott L. T., Landaverde R et Nolasso R., 1993. Traditional fallow systems of the Americas. Agroforestry systems 23:207-218.

Kaya B. 2004. Projet Collaboratif IER/ICARF, rapport d'étape 1995-2003. 10ème session du Comité de Programme de l'IER, ICRAF Samanko, 51 p.

Kébé, D., 1989. Les relations agriculture-élevage et le devenir des systèmes de production, Fonsebougou, Sud-Mali. Mémoire du Diplôme d'Etude Approfondie (DEA), Ecole Nationale Supérieure Agronomique de Montpellier (Ensam-Montpellier). 64 p.

Kelly, V., Reardon, T., Yanggen, D., and Naseem, A. 1998. Fertilizer in Sub-Saharan Africa: Breaking the vicious circle of high prices and low demand. Policy Synthesis 32. USAID. Washington D.C., USA.

Kidron, G.J., Karnieli, A., Benenson, I. 2010. Degradation of soil fertility following cycles of cotton–cereal cultivation in Mali, West Africa: A first approximation to the problem. Soil & Tillage Research 106 :254–262.

Kieft, H., N. Keita & A. Van der Heide, 1994. Engrais fertiles? Vers une fertilité durable des terres agricoles au Mali. ETC, Leusden, The Netherlands. 99 p.

Kouyaté, Z. and Wendt, G.W. 1991. Gestion de l'eau et de la fertilité du sol au Mali. Soil Water Balance in the Sudano-Sahelian Zone (Proceedings of the Niamey Workshop, February 1991). IAHS Publ. no. 199.

Laflen, J. M., and E. Roose. 1998. Methodologies for assessment of soil degradation due to water erosion, pp. 31–55, in R. Lal, W. H. Blum, C. Valentin, and B. A. Stewart, eds.,Methods for assessment of soil degradation. Advances in Soil Science, CRC Press, Boca Raton.

Lal, R. 1998. Soil erosion impact on agronomic productivity and environment quality. Critical revue. Plant Sciences 17:319–464.

Landais, E., P. Lhoste & H. Guerin, 1991. Systèmes d'élevage et transferts de fertilité. In: Savanes d'Afrique, terres fertiles? Centre de coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), p 219-270.

Lawarnou, M., Abdoulaye, M., Reij, C. 2006. Etude de la régénération naturelle assistée dans la région de Zinder (Niger). International Resources Group.Washington. 56 p.

Louppe, D., Ouattara, N.K. Olivier, R. 1998. Maintien de la fertilité dans trois jachères arborées. Bilan minéral (Korhogo, nord Côte d'Ivoire). Agriculture et Développement, 18:47-54.

MA (Ministère de l'Agriculture). 2012. Synthèse du plan de campagne 2012/2013. 6è Session du Conseil Supérieur de l'Agriculture. Secrétariat Général. 51 p.

Makken, F., 1993. Vue d'ensemble du secteur agricole en Afrique sub-saharienne. In: H. van Reuler & W.H. Prins (eds). Rôle de la fertilisation pour assurer une production durable des cultures vivrières en Afrique sub-saharienne. VKP, p 29-40.

Mando, A. 1997. The effect of mulch on the water balance of Sahelian crusted-soils. Soil Technology 11:121-138.

MDR (Ministère du Développement Rural). 2002. Plan national pour la gestion intégrée de la fertilité des sols au Mali. Secrétariat Général. 82 p.

MDR (Ministère du Développement Rural). 2002. Plan national pour la gestion intégrée de la fertilité des sols au Mali. Secrétariat Général. 82 p.

MEATEU/DNCN. 2001. Etude prospective du secteur forestier en Afrique.

MEME (Ministère de l'Energie, des Mines et de l'Eau). 2007. Plan d'Action National de Gestion Intégrée des Ressources en Eau. Rapport Final. Bamako. 146 P.

Morgan, R.P.C.1995. Soil erosion & conservation, 2nd edition Longman, Addison

Niangado, O., 1998. Agriculture sahélienne: situation actuelle et perspective d'un développement durable. In: H. Breman & K. Sissoko (eds). L'intensification agricole au Sahel. p 858- 876.

Nzuma, J.K. & K.H. Murwira, 2000. Improving management of manure in Zimbabwe. Managing Africa's soils N°15, 20 p.

Perrier, E.R., 1987. Adaptation of water management practices to rainfed agriculture on alfisols in ths Sahel. In: J.M. Menyonga, T. Bezuneh & A. Youdcowei. Food grain production in semi- arid Africa. p 445–464.

Pieri, C., N. Sharma & I. Valencia, 1998. Investir dans la fertilité des terres, un défi majeur pour l'avenir de l'Afrique sub-saharienne. In: H. Breman & K. Sissoko (eds). L'intensification agricole au Sahel. p 877-893.

Pieri, C., 1991. Les bases agronomiques de l'amélioration et du maintien de la fertilité des terres de Savanes au sud du Sahara. In: Savanes d'Afrique terres fertiles? Actes des Rencontres Internationales, Montpellier, France, 10-14 décembre 1990. p 43-73

Pieri, C. 1989. Fertilité des terres de savanes. Bilan de trente ans de recherche et de développement agricoles au sud du Sahara. Paris, Ministère de la Coopération et CIRAD IRAT.

Pieri, C. 1973. La fumure des céréales de culture sèche en République du Mali.

Agronomie Tropicale 28:751-766.

Pol, F. van der & F. Giraudy, 1993. Etude sur la relation entre pratiques d'amélioration des sols et variables socio-économiques dans la zone Mali-Sud. CMDT/KIT/IER, 26 p.

Poulain, J.F. 1976. Amélioration de la fertilité des sols agricoles du Mali. Bilan de treize années de travaux (1962-1974). Agronomie Tropicale 31:402-416.

Rajamani, V. 2005. Current Science 89, 850–852.

Reij. C., I. Scoones, and C. Toulmin. 1996. Sustaining the soil: Indigenous soil and water conservation in Africa, Earthscan, London.

Sanchez, P. A., K. D. Shepherd, M. J. Soule, F. M. Place, R. J. Buresh, A. M. N. Izac, A. U. Mokwunye, F. R. Kwesiga, C. G. Ndiritu, and P. L. Woomer. 1997. Soil fertility replenishment in Africa: An investment in natural resource capital, pp. 1-46, in R. J. Buresh, P. A. Sanchez, and F. Calhoun, eds., Replenishing soil fertility in Africa. SSSA Special Publication 51. Soil Science Society of America, Madison, WI.

Sanogo. B. 1997. Effet de l’azote et du phosphore sur l’efficacité agronomique des feuilles de *Gliricidia sepium* enfouies. Mémoire de fin d’étude d’Ingénieur de l’Institut Polytechnique Rural de Katibougou IPR/IFRA, Mali 44 p.

Sanogo, M.O. 2011. Le lait, de l’or blanc? Thesis, Wageningen Agricultural University, NL. 153 p.

Sidibé, D.K. 2010. Improving the management and productivity of Tamarindus indica and Ziziphus mauritiana in agroforestry parklands systems in Mali, West Africa. PhD thesis, Univ. of Wales, Bangor, United Kingdoms.

Sissoko, K. & H. Breman, 1998. Introduction générale. In: H. Breman & K. Sissoko (eds). L'intensification agricole au Sahel. p 15-21.

Smailing E.M.A. 1993. An Agro-ecological framework of integrated of Nutrient Management with special reference to Kenya. Wageningen Agricultural University, Wageningen.

Sterk, G. & L. Stroosnijder, 1998. Optimising mulch application for wind erosion protection in the Sahel. In: G. Renard, A. Neef, K. Becker & M. von Oppen (eds). Soil fertility management in West African land use systems. Gestion de la fertilité des sols dans les systèmes d’exploitation d’Afrique de l’Ouest. Proceedings regional workshop, University of Hohenheim, ICRISAT Sahelian Centre and INRAN, Niamey, Niger, 4-8 march 1997. p 185-189.

Stoorvogel, J.J., Smaling, E.M.A. 1990.Assessment of soil nutrient depletion in sub-Saharan Africa 1983–2000.Report 28; Winand Staring Centre for Integrated Land, Soil, and Water Research (SC-DLO). Wageningen.

Tangara. D. 1996. Possibilité d'utilisation d'arbustes comme source d'engrais vert dans la production du sorgho à Samanko, Mémoire de fin d'étude de Technicien Supérieur de l'Institut Polytechnique Rural de Katibougou IPR/IFRA, Mali 28 p.

TECSULT INTERNATIONAL LIMITEE, 2001. Plan Directeur d'assainissement de la ville de Bamako, Rapport Final. Ministère des Mines, de l'Hydraulique et de l'Energie.

Tilander, Y., Bonzi, M. 1997. Water and nutrient conservation through the use of agroforestry mulches, and sorghum yield response. Plant and Soil 197, 219-232.

Traoré, S.; Bagayoko, M.; Coulibaly, B. S.; Coulibaly, A. 1999. Amélioration de la gestion de la fertilité des sols et celle des cultures dans les zones sahéliennes de l'Afrique de l'Ouest: une condition sine qua none pour l'augmentation de la productivité et de la durabilité des systèmes de culture a base de mil.

Traoré, G., 1998. Politiques d'intensification agricole au Sahel. In: H. Breman & K. Sissoko (eds). L'intensification agricole au Sahel. p 801- 805.

Traoré KB, Gigou JS, Coulibaly H, Doumbia MD. 2004. Contoured ridge-tillage increases cereal yields and carbon sequestration. In:*Conserving Soil and Water for Society: SharingSolutions.*Papern°126. 13th International Soil Conservation Organisation Conference Brisbane.

Van Der Pol, F., Traoré, B. 1993. Soil Nutrient depletion by agricultural production in Southern Mali. Fertilizer Research **36**: 79-90.

Yossi, H., Traoré, H., Dembélé, F. 2002. Mise au point de technologies agroforestières appropriées RFO 11. Rapport final. IER Sikasso, Mali.

Yossi, H., B. Kaya, M. Sanogo, M. Karembe, B. Sanogo, I.L. Diarra & B.I. Diarra, 2000.Utilisation optimale de *Stylosanthes hamata* seul ou associé aux ligneux pour l'amélioration de la jachère en zone Mali- Sud. Atelier de restitution des acquis scientifiques et techniques du projet de recherche sur l'amélioration et la gestion de la jachère en Afrique de l'Ouest. Bamako, Mali, 29-31 Mai, 12 p.

Zerome, M. 2000. Evaluation de l'effet de l'engrais vert de *Tithonia diversifolia* sur *Amaranthus viridis* et *Zea mays* dans le périmètre maraîchers de Lafiabougou (District de Bamako et de Samaya (Région de Koulikoro). Mémoire de fin d'étude d'Ingénieur de L'Institut Polytechnique Rural de Formation et de Recherche Appliqué IPR/IFRA de Katibougou, Mali, 46 p.

Zougmoré, R., Kambou, N.F., Zida, Z. 2003. Role of nutrient amendments in the success of half-moon soil and water conservation practice in semi-arid Burkina Faso. Soil and Tillage Research 71, 143-149.

Zougmoré, R., Mando, A., Stroosnijder, L. 2010. Benefits of integrated soil fertility and water management in semi-arid West Africa: an example study in Burkina Faso. Nutr. Cycl. Agroecosyst. 88:17-27.

Zougmoré, R., Mando, A., Stroosnijder, L. 2009. Soil Nutrient and Sediment Loss as Affected by Erosion Barriers and Nutrient Source in Semi-Arid Burkina Faso. Arid Land Research and Management, 23:85

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