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IMPACT OF TILLAGE AND SOIL AMENDMENTS ON CEREAL PRODUCTION IN THE SAHELIAN ZONE OF MALI

BY

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JULY, 2014

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MASTER OF SCIENCE

IN

SOIL SCIENCE

BY
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JULY, 2014

DECLARATION

I hereby declare that this submission is my own work toward the MSc degree and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

A field study was carried out at Sikidolo in the Sahelian zone of Mali to assess the impact of tillage and soil amendments on the growth and yield of millet and sorghum. Two experiments were conducted for millet and for sorghum. The treatments consisted of two tillage practices (contour ridge and hoe tillage) and five soil amendments (organic manure, urea, rock phosphate and lime). The experiment was factorial in RCBD with 3 replications. The contour ridge outyielded the hoe tillage in most of the measured parameters. The respective percentage increment under millet and sorghum were 12.5 and 9 % for plant height, and 12 and 61 % for grain yield. Millet biomass yield and nitrogen use efficiency (NUE) were increased by 65 % and 316 % respectively by contour ridge. Contour ridge did not significantly ($p<0.05$) influence soil pH, exchangeable K, and available phosphorus, although it had higher values than the hoe tillage and significantly increased soil organic carbon under millet (48 %) and sorghum (15 %). The application of manure increased sorghum height by 94 %, grain yield by 576 % and biomass yield by 162 % while it increased millet height by 61 %, grain yield by 112 % and biomass yield by 198 % relative to the no amendment. The application of manure for both millet and sorghum did not significantly ($p < 0.05$) affect soil chemical properties, although soil organic carbon value was highest with the application of manure. The integrated use of manure and inorganic fertilizers increased sorghum and millet growth, yield and NUE relative to the application of the manure but did not significantly increase soil chemical properties relative to the application of manure alone. With a value cost ratio (VCR) less than 2.0, all the treatments were not economically profitable. However, on a relative basis, the application of manure was promising with a VCR of 1.8 and 1.0 under millet and sorghum respectively. Based on grain yield and corresponding absolute monetary value, the contour ridge was more profitable than the hoe tillage.

DEDICATION

I dedicate this thesis to Dr. Mamadou D. Doumbia who fell sick at the commencement of the research work.

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CHAPTER ONE

1.0 INTRODUCTION

Mali is one of the countries in the Sudano-Sahelian zone of West Africa where the general decline in soil fertility is a major constraint to agricultural productivity (Kouyaté *et al.,* 2000). Rather than increasing soil productivity, current farmer practices such as hoe tillage, conventional tillage, and no or insufficient application of amendments continue to mine the soil nutrients. Yields of sorghum and millet obtained by the application of low doses of manures and mineral fertilizers have led to continuous depletion of soil nutrients.

In recent years, both drought and demographic pressures have put enormous strain on the natural environment of Mali. Tree and grass cover have dwindled, with disastrous consequences for the soil, which is left bare to the erosive winds and rains of the tropics. Soil erosion and farming activities that extract nutrients from the soil have caused severe soil degradation in Mali, threatening food security. Although, the region receives substantial rainfall, yet much, is lost during intense storms on soils with low infiltration rates.

Efforts to address these problems have been directed at assessing the impact of tillage and soil amendments on soil and water conservation and crop yield and of a particular importance is the use of contour ridges (CR) in the cultivation of cereals. Contour ridge is a holistic landscape approach to manage water and capture rainfall on a watershed scale (Gigou *et al.,* 2006). It is a technology developed locally by the Institut d'Economie Rurale (IER) and CIRAD (Gigou *et al.,* 2006). Doumbia *et al.* (2009) reported that CR retains rainfall and improves water availability for crops and enhances soil carbon sequestration. According to him it increased deep drainage and ground water recharge and increased soil organic concentration after 3 years. Traoré *et al.* (2002) summarized the expected benefits of the CR on soil carbon to include the following: (1) reduced erosion losses of soil and residue C, (2) increased growth of trees and crop, especially those that annually shed their leaves, (3) increased crop yields due to increased soil moisture, and (4) forage and building material from grasses that stabilize permanent ridges and waterways.

Julio and Carlos (1999) indicated that in Mali the agriculture soils are characterized by low land productivity associated with poor rainfall, low soil fertility, and traditional crop management practices. They indicated that judicious use of manure, mineral fertilizer and lime may be a credible option for improving soil fertility and crop yield. Their findings concerning the agronomic and economic performance of phosphate sources in Mali indicate that phosphate fertilizers are indeed needed for the production of food and cash crops and that Tilemsi phosphate rock (TPR) is a suitable indigenous source of phosphorus (P) for the sustainability of important cropping systems in Mali.

However, the beneficial effects of the combined use of mineral fertilizers and farmer’s animal manure under different tillage practices have received less research attention. The use of the indigenous, rock phosphate (RP) in crop production is also less studied. Yet such studies are needed to yield the requisite baseline information for introducing RP into the farming system of small holder farmers. It is in this context that this study was carried out.

The general objective of the study was to contribute to improved productivity of cereal cropping systems in Mali through improved tillage and soil amendments.

The specific objectives were to:

i. assess the effect of tillage and amendments on growth and yield of millet and sorghum.
ii. evaluate the effect of tillage and soil amendments on soil chemical properties.
iii. assess the effect of tillage and soil amendments on nitrogen use efficiency (NUE) of millet.
iv. determine the cost effectiveness of soil amendments and tillage practice in the study area.

The above specific objectives were formulated to test the hypothesis that:

i. The use of the contour ridge (CR) technology would improve soil fertility and grain yield on degraded land at Sikidolo in Mali.
ii. The application of organic manure and mineral fertilizers would improve soil fertility and crop productivity.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Types of soil tillage practices

Soil tillage is a method of soil preparation for seedbed preparation, sowing or transplanting, and for crops' growth. A number of modified tillage practices have been developed for providing a better soil and water - plant relations, reducing runoff as well as soil erosion by enhancing infiltration capacity of the soil. Tillage practices can be broadly classified into: no-tillage (slot planting), mulch tillage, strip or zonal tillage, ridge till (including no-till on ridges) and reduced or minimum tillage.

2.1.1 No-tillage

The no-till system is a specialized type of conservation tillage consisting of a one-pass planting and fertilizer operation in which the soil and the surface residues are minimally disturbed (Parr *et al*., 1990). The surface residues of such a system are of critical importance for soil and water conservation. Weed control is generally achieved with herbicides or in some cases with crop rotation. According to (Lal, 1983), no-tillage systems eliminate all replanting mechanical seedbed preparation except for the opening of a narrow (2-3 cm wide) strip or small hole in the ground for seed placement to ensure adequate seed/soil contact. The entire soil surface is covered by crop residue mulch or killed sod. A review of tillage studies in Nigeria (Opara, 1990) shows that no-tillage with residue mulch is appropriate for Luvisols in the humid tropics. No-tillage is used in mechanized wheat farming in northern Tanzania and for some perennial crops, for example coffee plantations (Antapa and Angen, 1990). Several studies (Parr *et al*., 1990) have reported the success of no-tillage systems in many parts of the USA. Though the use of no-till is increasing, adoption has been slow. Parr *et al*. (1990) reported that in the USA, no-till is practiced on less than 10% of the farmland that is in some form of conservation tillage.

No-till fallow is a type of no-tillage system which is used in the dry land areas. No-till fallow has been most successful in summer rainfall areas (Parr *et al*., 1990). A major goal of fallowing is to recharge the soil profile with water so that the risk of failure for the next crop is greatly reduced (Unger *et al*., 1988). According to Parr *et al*. (1990), the potential benefits of no-till fallow, compared with other tillage systems, are more effective control of soil erosion, increased water storage, lower energy costs per unit of production and higher grain yields. A major disadvantage of no-till fallow (sometimes referred to as chemical fallow) is its heavy use of herbicides for weed control.

2.1.2 Mulch tillage

Mulch tillage techniques are based on the principle of causing least soil disturbance and leaving the maximum of crop residue on the soil surface and at the same time obtaining a quick germination, and adequate stand and a satisfactory yield (Lal, 1986). Lal (1986) further reported that a chisel plough can be used in the previously shredded crop residue to break open any hard crust or hard pan in the soil whilst ensuring that no crop residues are incorporated into the soil. The use of live mulch and crop residue *in situ* involves special mulch tillage techniques or practices. *In situ* mulch, formed from the residue of a dead or chemically killed cover crop left in place (Wilson, 1978), is generally becoming an integral component of mulch tillage techniques.

2.1.3 Strip or zonal tillage

The concept of strip or zonal tillage is described by Lal (1983). The seedbed is divided into a seedling zone and a soil management zone. The seedling zone (5 to 10 cm wide) is mechanically tilled to optimize the soil and micro-climate environment for germination and seedling establishment. The inter row zone is left undisturbed and protected by mulch. Strip tillage can also be achieved by chiseling in the row zone to assist water infiltration and root proliferation.

2.1.4 Reduced or minimum tillage

This system covers other tillage and cultivation systems not covered above but meets the 30% residue requirement (Laryea *et al*., 1991). In Africa, the term minimum tillage is not always employed with the same meaning as in temperate countries, and may also be used differently in the different contexts of shifting cultivation (still the dominant system in most of Africa) and mechanized agriculture (Ahn and Hintze, 1990).

2.1.5 Hoe tillage

Hoes and spades in different shapes and weights are the tools used for hand-tillage operation, unless contract ploughing with animals or tractors is used. Tillage depth and intensity with hand tools is very limited, but as it also leaves the soil exposed it will equally lead to soil degradation and erosion (FAO, 2014). Even the creation of compaction zones (hoe-pans) is known. Tillage tools might still be necessary for some specialized operations even under conservation agriculture, such as reshaping beds or maintaining irrigation ditches. However, under conservation agriculture there is no general tillage anymore and farmers use direct seeding to plant the crop. With this the main bottleneck of labour availability for land preparation is eliminated

(FAO, 2014). Hoeing for land preparation is eliminated with conservation agriculture (CA), and with the major labour bottleneck in the cropping season (FAO, 2014). Hoeing with hand-held implements during plot preparation, sowing, and weeding is an important agent of tillage erosion on sloping lands in developing countries (Alan, 2012). Zhang *et al.* (2009) suggested that non-overturning hoeing tillage largely diminishes soil downslope translocation and results in a significant reduction in tillage erosion.

2.1.6 Contour ridges (CR)

Contour ridges sometimes called contour furrows or micro watersheds, are used for crop production. Ridges follow the contour at a spacing of usually 1 to 2 meters. Runoff is collected from the uncultivated strip between ridges and stored in a furrow just above the ridges. Crops are planted on both sides of the furrow (Jack, 2012).

The yield of runoff from the very short catchment lengths is extremely efficient and when designed and constructed correctly there should be no loss of runoff out of the system. Another advantage is an even crop growth due to the fact that each plant has approximately the same contributing catchment area (Jack, 2012).

Since the contour ridge technique implies a new tillage and planting method compared with conventional cultivation, farmers may be initially reluctant to accept it (Jack, 2012). Demonstration and motivation are therefore very important to enhance its acceptance or adoption. On the other hand, it is one of the simplest and cheapest methods of water harvesting. It can be implemented by the farmer using a hoe, at no or little extra cost. External support is limited to a minimum. Alternatively it can be mechanized and a variety of implements can be used. When used by a farmer on his own land, the system does not create any conflicts of interest between the implementer and the beneficiary (Jack, 2012).

2.2 Effect of tillage practices on grain yield of cereals

Contour ridge technology was developed in Mali and has been beneficial in several West African countries such as Senegal and Gambia. Contour ridge increased maize yield by 38 %, sorghum by 39 % and cotton yields by 7 % in Mali peanut and sorghum yields by 25 % in Senegal and maize yield in Gambia from 9 to 30 % (Doumbia *et al.*, 2008). The semi-arid zone has the highest prospects for rapid tillage technological package development, firstly, because of the availability of animal draught power, secondly because of the crops and cropping systems used and, thirdly because of the rapid response of the zone to soil and water conservation and management practices to increase crop production (Ofori, 2013). At Al-Majjediah village the biomass yield of maize was 517.47 kg ha^{-1} for contour ridge method, 422.23 kg ha^{-1} for traditional method and 351.73 kg ha^{-1} for strip method, in addition, straw yield was 447.70 kg ha^{-1} for contour ridge, 315.36 kg ha^{-1} for traditional and 253.23 kg ha^{-1} for strip methods, respectively (Yahya, 2013).

The yield increase is around 30 % and higher in dry years, the contour ridges significantly increased maize yield by 35 % and millet yield by 60 % in Mali (Jacques *et al.*, 2006). Hilger (2008) reported that after three years of experiment, maize yield increases for soil tillage treatments reached 2.0 to 2.7 Mg ha^{-1} without fertilizer and 3.9 to 4.2 Mg ha^{-1} with fertilizer application

2.3 Effect of tillage practices on chemical and physical properties of soil

The principal objective of the CR technology is to retain or capture rainfall on the field, which helps to overcome the typically low infiltration rate of the soils (Kablan *et al.*, 2008). This retention of water reduces destructive runoff and enables multiple uses of the captured rainfall. As a result of the increased infiltration of rainfall, water availability increases, improving crop growth and reducing erosive runoff as shown in long-term studies initiated by Gigou *et al.* (2006). Findings document increased soil water content resulting in increased crop yields. Yields may increase as much as 50 % for millet, sorghum, and maize (Gigou *et al.*, 2006). Contour ridge reduced runoff of seasonal rainfall by 26 %, increased soil moisture in crop root zone by 16 % and available moisture for deep rooted plants by 64 % and ground water recharge by 29 % on the other hand contour ridge increased deep drainage and ground water recharge and increased soil organic concentration by 14 % after three years in Senegal (Doumbia *et al.*, 2008). Doumbia *et al.* (2009) evaluated the potential impact of CR on crop yield and soil carbon sequestration in Mali, and observed that CR retains rainwater and improves water availability for crops whilst improving soil carbon sequestration. Tillage has various physical, chemical and biological effects on the soil both beneficial and degrading, depending on the appropriateness or otherwise of the methods used (Ofori, 2013). Soil and water conservation, in particular, have direct influence on the physical properties of the soil such as aggregate-stability and infiltration rate leading to improved soil productivity and sustainability (Ofori, 2013). Tillage work carried out in Africa has been mainly in the semi-arid and sub-humid agro-ecological zones. Relatively little data is available for the humid tropics (Ofori, 2013). Average cumulative N losses by runoff, soil loss and leaching were reduced from 55 kg ha^{-1} in the control to 37-40 kg ha^{-1} in the barrier treatments

(Pansak, 2007). Although the total and available $CaCO_3$, depends on the sampling depth, it was slightly higher in the control plot relative to the contour ridge benches (Pansak, 2007). Findings show that soil fertility varied according to land management, whereby a soil under forest reserve had deep A horizon and was rich in total exchangeable bases (11.80 $cmol_c\ kg^{-1}$ soil) and high in exchange property while that under continuous cultivation had low fertility with a total exchangeable bases of 3.28 $cmol_c\ kg^{-1}$ soil (Pansak, 2007). When compared with the conventional management, sediment phosphorus losses were significantly reduced from plots of contour hedgerows of *Vetiveria zizanioides* by 46.61 %, contour hedgerows of alfalfa by 30.51 %, and ridge furrows cultivation by 37.29 % (Lin, 2007). Surface runoff total phosphorus loss was reduced on plots of contour hedgerows of *Vetiveria zizanioides*, 45.38 %, 28.46 % and 34.62 % respectively (Lin, 2007).

2.4 Effect of soil organic and inorganic fertilizers on soil properties

Chemical fertilizers are used in modern agriculture to correct known plant-nutrient deficiencies; to provide high levels of nutrition, which aid plants in withstanding stress conditions; to maintain optimum soil fertility conditions; and to improve crop quality. Adequate fertilization programs supply the amounts of plant nutrients needed to sustain maximum net returns (Bekeko, 2014). In essence, fertilizers are used to make certain that soil fertility is not a limiting factor in crop production. High soil organic matter concentrations have been proved to enhance the yield components of cereals (Sarwar, 2005) as well as soil aeration, soil density and maximize water holding capacity of soil for seed germination and plant root development (Zia *et al.*, 1998).

2.4.1 Soil organic carbon (SOC)

The highest increasing (2.17 %) in SOC was observed under application of 80 t farm yard manure after four years than 40 t farm yard manure, 40 t FYM + equivalent NPK, 80 t FYM and the control application. Long-term applications of animal manure increased soil organic matter in two ways: (1) by adding OM contained in the manure and (2) by increased organic matter in crop residues due to higher crop yields in soils receiving manure (Whalen and Chang, 2002). The added benefits or disadvantages of combined nutrient applications may therefore be due to the decomposition rate, the availability of C for microbial growth and hence the quality of the organic manures (Palm *et al.*, 1997). Although evidence of added benefits from the combined use of organic and mineral fertilizer have been reported by Sakala *et al.* (2000) the mechanisms by which these added benefits occur is not precisely understood (Gentile *et al.*, 2008). Giller (2002) suggested the stimulation (priming effect) of decomposition and nutrient release by the addition of a labile C or N as a possible mechanism. He, however, admitted that there was scanty evidence to support true priming effect of agronomic significance. Wu *et al.* (2008) observed that the application of NPK remarkably improved SOC by 22 % while organic manure resulted in the highest SOC (72.5 %) higher than the control. The average amounts of C/N ratio ranged from 9.66 to 10.98 in different treatments, and reached the highest in organic manure treatment ($P< 0.05$) (Wu *et al.*, 2008). Hati *et al.* (2006) reported the application of 10 Mg farmyard manure and recommended NPK rate (NPK+FYM) to soybean for three consecutive years improved the organic carbon content of the surface (0-15 cm) soil from an initial value of 4.4 g kg^{-1} to 6.2 g kg^{-1}. Wells *et al.* (2000) reported that soil organic carbon was decreased by chemical fertilizer application alone but was increased with all types of organic manure application alone and that was recorded the highest with combined application of organic manure and chemical fertilizers.

2.4.2 Nitrogen (N)

The observation by Vanlauwe *et al.* (2002) that incorporation of maize residues with urea fertiliser reduced the leaching of urea-N while the incorporation of urea with *Mucuna pruriens* residues led to greater leaching of urea N supports the direct hypothesis of immobilization reducing N losses. The resulting improved yields were attributed to improved soil moisture conditions under the combined treatment. Gentile *et al.* (2008) studied the interactive effect of ^{15}N-enriched crop residues and ^{15}N labeled urea on N transformation in a 545 day microcosm experiment. Their results indicated that mixing ^{15}N-enriched maize stover and unlabeled urea or ^{15}N urea and unlabeled maize stover immobilized urea-applied N and stimulated the release of maize stover-N. However, the retention of fertiliser-N (35 to 57 %) was greater than the release of residue-N, resulting in an overall negative interactive effect on an extractable mineral N. Considering the long term fertilizer efficiency, the results also suggested that annual straw application could improve soil fertility. Fertilization, being the main practice of crop management, has great impact on the fractions of soil organic N, directly through changing the composition of soil N and indirectly through affecting crop growth (Kelley and Stevenson, 1996)

2.4.3 Available phosphorus

Verde *et al.* (2013) reported that manure alone or combined with lime increased mostly the soil available P, depicting that the increase was not significant. Abera *et al.* (2005) also found higher soil extractable P with higher rate of manure application. The soils tested low in P (7.54 mg kg^{-1}) before the experiment was set and it was observed that the levels of P before planting were higher than after harvest under all treatments except sole manure (Verde *et al.,* 2013). The observation was attributed to the higher phosphorus fixation capacity of acid soils and to the uptake by plants. Jibrin *et al.* (2002) also reported extremely low concentration of P even with application of 60 kg P ha^{-1}. The soils on which the study was undertaken were moderately acidic (pH H_2O = 5.06; pH KCl = 4.21), therefore high P fixation was expected (Verde *et al.,* 2013). Also the little changes in soil available P even with application of P fertilizer was attributed to the method of application of the fertilizer (Kamara *et al.,* 2008), which was point placed rather than broadcasted, while the soil samples were taken between the rows.

2.5 Effect of organic, inorganic fertilizers, and lime on soil properties

Application of lime tends to raise soil pH by displacement of H^+, Fe^{2+}, Al^{3+}, Mn^{4+} and Cu^{2+} ions from soil adsorption site (Onwonga *et al.*, 2010). Lime also supplies significant amounts of Ca and Mg, depending on the soil type (Verde *et al.,* 2013). Plants only absorb potassium ions (K^+) in one form called exchangeable potassium, provided by moist clay particles or organic matter (James, 2008). Since leaching of potassium is slow in soil, regular applications of potassium-rich fertilizers over long periods can increase amounts of exchangeable potassium in the soil (James, 2008). The results showed that manure applied at the rate of 10 t ha^{-1} or 5 t ha^{-1} combined with lime significantly reduced exchangeable acidity and increased soil pH; application of manure alone or combined with lime or P fertilizer also increased Mg and K; treatments that had sole lime, lime combined with manure and manure combined with P applied gave a significant increase in exchangeable Ca (Benvindo, 2013). The increase in soil pH and reduction in soil exchangeable acidity following application of manure and lime either sole or combined can be attributed to the release of organic acids (during mineralization of manure), which in turn can suppress Al content in the soil through chelation (Okwuagwu *et al.*, 2003). Moreover, lime when applied in the soil reacts with water leading to the production of OH^- ions and Ca^{2+} ions which displace H^+ and Al^{3+} ions from soil adsorption sites resulting in an increase in soil pH (Kisinyo *et al.*, 2012). Adeniyan *et al.* (2011) reported increase in soil pH following application of manure in Nigeria. Increased Mg availability in the soil as a result of manure application was also observed elsewhere by Adeleye *et al.* (2010) who attributed it to the release of nutrients through manure decomposition.

Rahman *et al.* (2002) also found increased available Mg in the soil as a result of applied manure either alone or in combination with lime and attributed the increase to improved Mg availability as a result of improved soil pH. The increase can be attributed to the release of Ca^{2+} ions in lime through its dissociation (Chimdi *et al.*, 2012) and to mineralization of manure with released nutrients (Shen and Shen, 2001). It was observed that application of manure either solely or in combination with P fertilizer and, both P fertilizer and lime had a positive effect on soil exchangeable K, due to release of K from the manure. Similar findings were reported by Chimdi *et al.* (2012). Soils tend to become acidic as a result of: (1) rainwater leaching away basic ions (calcium, magnesium, potassium and sodium); (2) carbon dioxide from decomposing organic matter and root respiration dissolving in soil water to form a weak organic acid; (3) formation of strong organic and inorganic acids, such as nitric and sulfuric acid, from decaying organic matter and oxidation of ammonium and sulfur fertilizers. Strongly acid soils are usually the result of the action of these strong organic and inorganic acids (Anon, 2014).

Lime is usually added to acid soils to increase soil pH. The addition of lime not only replaces hydrogen ions and raises soil pH, thereby eliminating most major problems associated with acid soils but it also provides two nutrients, calcium and magnesium to the soil (Robert, 2007). Lime also makes phosphorus that is added to the soil more available for plant growth and increases the availability of nitrogen by hastening the decomposition of organic matter. Liming materials are relatively inexpensive, comparatively mild to handle and leave no objectionable residues in the soil (Robert, 2007). As soil acidification occurs, soil chemical and biological properties change (Anderson *et al.,* 2013). One chemical change is increased solubility of aluminum (Al) and manganese (Mn), both of which can be toxic to plants. Plants vary in their tolerance of Al and Mn, creating crop-specific soil pH requirements (Hart *et al.,* 2013). On most acid soils, there are several limiting factors for plant growth, including toxic levels of Al, Mn, and iron (Fe), as well as deficiencies of some essential elements, such as phosphorus (P), nitrogen (N), potassium (K), calcium (Ca), Mg, and some micro nutrients (Kochian *et al*., 2004). Among these constraints, Al toxicity and P deficiency are the most important due to their ubiquitous existence and overwhelming impact on plant growth (Kochian *et al*., 2004). Soil pH is one of the most important soil properties that affect the availability of nutrients. Macro nutrients tend to be less available in soils with low pH. Micronutrients tend to be less available in soils with high pH. Lime can be added to the soil to make it less sour (acid) and also supplies calcium and magnesium for plants use (NCDACS, 2011). Rahman *et al*. (2002) reported that application of lime influenced nutrient availability of soil, resulting in increased yield and yield components of both anaerobic rice and yearly aerobic wheat cropping system. In another study (Okalebo *et al.*, 2004) the application of wheat straw and soybean haulms with urea on an acidic Ferralsol (pH–water of 4.9) yielded added benefits of 684 kg grain ha^{-1} which could be explained by the increase in soil pH (to 5.4, on average) following the addition of organic residues. Yadav *et al*. (2002) reported that soil pH decreased with organic manures application and combined application but increased with only chemical fertilizer application. Mukuralinda (2011) reported lime led to significant increases in soil pH followed by manure of *Tithonia* combined with triple superphosphate (TSP) at a rate of 50 kg P ha$^{–1}$. Opala (2012) reported at Kakamega, all the manure of *tithonia diversifolia* treatments with the exception of Tithonia (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1}) and *Tithonia* (20 kg P ha^{-1}) significantly increased the soil pH than the control, and farmyard manure (FYM) when applied alone or in combination with the inorganic P sources generally increased soil pH, although statistical significance was not always attained. Simek *et al.* (1999) reported soil pH was increased or unaffected by the addition of organic manure plus inorganic fertilizers applied in conjunction with lime, but decreased in the absence of liming. Yaduvanshi (2003) indicated that the residual effect of green manure or FYM plus the full recommended fertilizer amount (120 kg N, 26 kg P and 42 kg K ha^{-1}) was significantly greater than that of the full recommended amount of fertilizer. Addition of green manure or FYM resulted in higher nutrient removal in crops, increase of soil N, P, K and organic C, and reduced soil pH.

2.6 Effect of organic and mineral fertilizers on grain yield of cereals

Many scientists have reported substantial yield increases from manure application in West Africa (Bationo *et al.,* 1995; Agbede and Ojeniyi, 2009). As crop responses varied widely even between different seasons within the same study, the conclusions from these studies were highly site and season specific. In a study to evaluate the effect of nutrient cycling practices in western Niger on the yield of millet, Ikpe and Powell (2002) reported that grain yield was highest (1600 kg ha^{-1}) in plots where the kraaling of sheep directly on the cropland for the application of dung and urine was simulated. According to him yields were 1400 kg ha^{-1} and 1000 kg ha^{-1} on manure and non-manure plots. The enhanced yield as a result of kraaling was attributed to immediate incorporation of manure and thus minimum loss of N through volatilization as well as the additional N supplied by the application of urine. Agbede and Ojeniyi (2009) reported that the application of manure at 7.5 t ha^{-1} in the forest-savanna transition zone of Nigeria for 3 years significantly increased sorghum yields from 1.24 t ha^{-1} (on control plots) to 1.72 t ha^{-1}. In the Sudano-Sahelian zone of Burkina Faso, Mando *et al.* (2005) found that the continuous application of manure of 10 t ha^{-1} for a decade also increased sorghum grain yield from 460 to 2618 kg ha^{-1}. The application of adequate amounts of manure may sufficiently replace the use of chemical fertilizer Mando *et al.* (2005). In the Sahelian zone of West Africa, Bationo and Mokwunye (1991) established that the application of 20 t FYM ha^{-1} produced as much millet as the yields obtained by the recommended chemical fertilizer rate. In a recent study, Shisanya *et al.* (2008) also reported that the application of cattle manure at rates equivalent to 60 kg N ha^{-1} gave significantly higher yield (4.1 t ha^{-1}), which was comparable to yields (4.2 t ha^{-1}) obtained from mineral fertilizer applied at the same rate. Many scientists suggested that the use of organic matter along with chemical fertilizers can give higher grains yield than obtained with synthetic chemical fertilizers alone (Sarwar *et al.*, 2008). Higher soil organic matter concentrations have been proved to enhance the yield components of cereals (Sarwar, 2005). The combined application of organic and mineral nutrient sources may lead to synergistic, antagonistic or additive effects on crop production (FAO, 2003). David (2009) reported that the application of lime, and lime plus DAP increased maize grain and stover yields; for lime application grain yield was 3.6 t ha^{-1}, for lime + DAP application grain yield was 3.1 t ha^{-1} and for farmers' practices grain yield was 2.2 t ha^{-1}; for lime application stover yield was 4.44 t ha^{-1}, for lime + DAP application stover yield was 3.97 t ha^{-1}, and for farmers' practices stover yield was 3.37 t ha^{-1}.

2.7 Effect of soil amendments and tillage on nitrogen use efficiency

2.7.1 Effect of organic and inorganic fertilizers and lime on nitrogen use efficiency

Worldwide, nitrogen use efficiency (NUE) for cereal production is approximately 33% (Raun and Johnson, 1999). Loss of fertilizer N results from gaseous N emission, soil denitrification, surface runoff, volatilization and leaching. Increased cereal NUE is unlikely unless systems approach is implemented that uses varieties with high harvest index coupled with incorporation of NH_4-N fertilizers application of prescribed rates consistent with in-field variability using sensor-based systems within production field. (Johnson, and William 1999). Not until recently have scientists documented that cereal plants realize N from plant tissue, predominantly NH_3 following anthesis (Francis *et al*., 1993). Plant N losses have accounted for 52 to 73 % of the unaccounted N using ^{15}N in corn research (Francis *et al*., 1993). Incorporation of straw and/or application of straw on the surface of zero till plot reduces denitrication losses (Johnson and William, 1999). Fertilizers N losses in surface runoff range between 1 % (Blevins *et al*., 1996), and 13 % (Chichester and Richardson, 1992) of the total N applied, and are generally lower under no-tillage. When urea fertilizers are applied to the surface without incorporation, losses of fertilizer N as ammonia can exceed 40 % (Fowler and Brydon, 1989), and generally greater with increasing temperature, soil pH, and surface residue. When fertilizers N is applied at rates in excess of that needed for maximum yield in cereal crops, nitrate leaching can be significant (Raun and johnson, 1995). Finding more efficient ways to fertilize crops will reduce N losses and increase nutrient uptake (Abdul *et al.,* 2011). In their study Abdul *et al.* (2011) found that low NPK (200-100-100 kg ha^{-1}) and medium NPK (250-125-125 kg ha^{-1}) rates performed equally well with respect to NUE; however, the high dose of NPK (300-150-150 kg ha^{-1}) decreased NUE (Abdul *et al.,* 2011). This indicates that NUE might be consistent with increasing the NPK dose up to a certain level. This is contrary to the observation of Pikul *et al.* (2005) that as applied N decreases, NUE continues to increase. There was a better efficiency of applied nutrients NUE during 2007 than in 2006; this might have resulted from better plant root growth due to more rainfall during the early crop growth period during 2007 (Abdul *et al.,* 2011). Zhang (2009) found that mixed organic and inorganic fertilizer treatments promoted rice N uptake and improved soil N supply, and thus, increased N use efficiency, compared with chemical fertilizer treatments. Yaduvanshi (2003) reported that applying inorganic fertilizers resulted in similar nitrogen use efficiency (NUE) in rice as compared with organic manures along with inorganic fertilizers, but NUE was increased in wheat by the residual effect of organic manures along with inorganic fertilizers. Nitrogen use efficiency can be increased by P fertilization, optimal soil phosphorus level in your soil should be between 30 and 40 lb/acre (Rocky, 2012).

2.7.2 Effect of contour ridge on nitrogen use efficiency NUE

Nitrogen use efficiency (when averaged over planting methods) was also the highest with ridge plantation, which indicates that this soil manipulation would have resulted in reduced/slower N losses (leaching), and that plant roots grow profusely to take up nutrients from a large soil volume (Abdul, 2011).

2.8 Effect of soil tillage and soil amendments on value cost ratio of cereals

Crawford *et al.* (2005) reported that while there has been considerable research and policy analysis on fertilizer promotion and use around the world, this has not been the case In Mali. There remain knowledge gaps, the state of fertility of Mali's soils; the yield response to fertilizer for key crops and, hence, the profitability of fertilizer use on them; the effectiveness of existing agricultural extension services in promoting fertilizer use; the potential effects of fertilizer subsidies on the private-sector fertilizer market development; and the likely effects of changing climatic conditions on the profitability of fertilizer use.

Stephen (2009) reported that the lack of such information on crop-fertilizer profitability across the country means that farmers cannot tell how much they stand to gain or lose by applying a particular type of fertilizer to a particular crop; this increases their risk and creates a disincentive for use of fertilizer. Information about profitability levels can serve as an incentive for inorganic fertilizer use. Most simply, expected Value Cost Ratios (VCR) from fertilizer use can guide farmers' decisions. The VCR refers to the value of additional crop yield obtained from using fertilizer divided by the cost of the fertilizer treatment. Kelly (2006) indicated that a VCR greater than two is generally considered an adequate incentive for fertilizer adoption since the financial returns to using fertilizer are two times greater than the cost.

MAAIF (2008) reported that due to lack of adaptive and economic research studies on crop-fertilizer combinations in the different parts of Uganda, available fertilizer use recommendations have not been updated in a long time. With changing input and output prices over time, this implies that the fertilizer applied to farmers' crops do not provide optimal economic returns to farmers. Since fertilizer is costly, less than optimal returns are likely to discourage fertilizer use. Stephen (2009) indicated that on the supply side, fertilizer traders in rural areas should be equipped with knowledge on appropriate fertilizer use so that they can pass on the right kind of information and products to the farmers purchasing fertilizer from them. According to Demeke *et al.* (1998), fertilizer use is low in SSA for varied reasons, including unattractive crop price/fertilizer price relationship, inadequate credit availability for both farmers and dealers, poor distribution facilities, limited irrigated agriculture, continued use of local crop varieties by most farmers and low incentive in investing in land-saving technologies given the relatively low population densities. The challenge with fertilizer is not limited to its low usage. Gregory and Bumb (2006) and Mwangi (1996) reported that most African farmers get low response rate from fertilizer application, i.e. relatively low production from every ton of fertilizer applied, due to inefficiency in application and/or the poor soil fertility condition. The low response rate, coupled with high fertilizer price and fluctuating crop price, has limited the profitability of fertilizer use and hence, the demand for it by smallholder farmers (Mwangi, 1996). Piha (1993) indicated that in semi-arid areas where variable rainfall causes highly variable returns to fertilizer use, the sub-optimal response rates contribute even further to lower demand. Morris *et al.* (2007) pointed out that the non-optimal use of fertilizer has also deteriorated soil quality on farmlands to such an extent that a recent World Bank study claims that SSA faces “an escalating soil fertility crisis”. Saa (2012) asserted that low and inefficient use of fertilizer are not only hindering the growth in agricultural productivity but also jeopardizing the long term sustainability of African soil and thereby, gravely undermining the prospects for ending chronic poverty and food insecurity in the region.

Ellis and Tengberg (2000) reported that to sustain food production on smallholder farms in developing countries, soil and water conservation (SWC) has been strongly promoted in almost every developing country over the last 50 years. Despite this, land degradation remains a major threat to agricultural production in many developing countries (Ellis and Tengberg, 2000), although there is an awareness that the underlying causes of land degradation are often social and economic in mature (Biot *et al.,* 1995). Soil erosion has conventionally been perceived as the chief biophysical cause of declining productivity. Yet, the limited effectiveness and low adoption of widely promoted anti-erosion measures make it necessary to reconsider the causes of productivity decline as well as to consider social and economic constraints of improving SWC practices (Ellis and Tengberg, 2000). In addition, it is useful to provide information about benefits of the water harvesting technology early in the adoption process to help promote adoption through the provision of appropriate educational and extension support to ensure that farmers have the knowledge necessary to implement the chosen technology (Critchley and Siegert, 1991). The Contour ridge system is one of the water harvesting technologies which is less costly and easily applied.

2.9 Summary of Literature Review

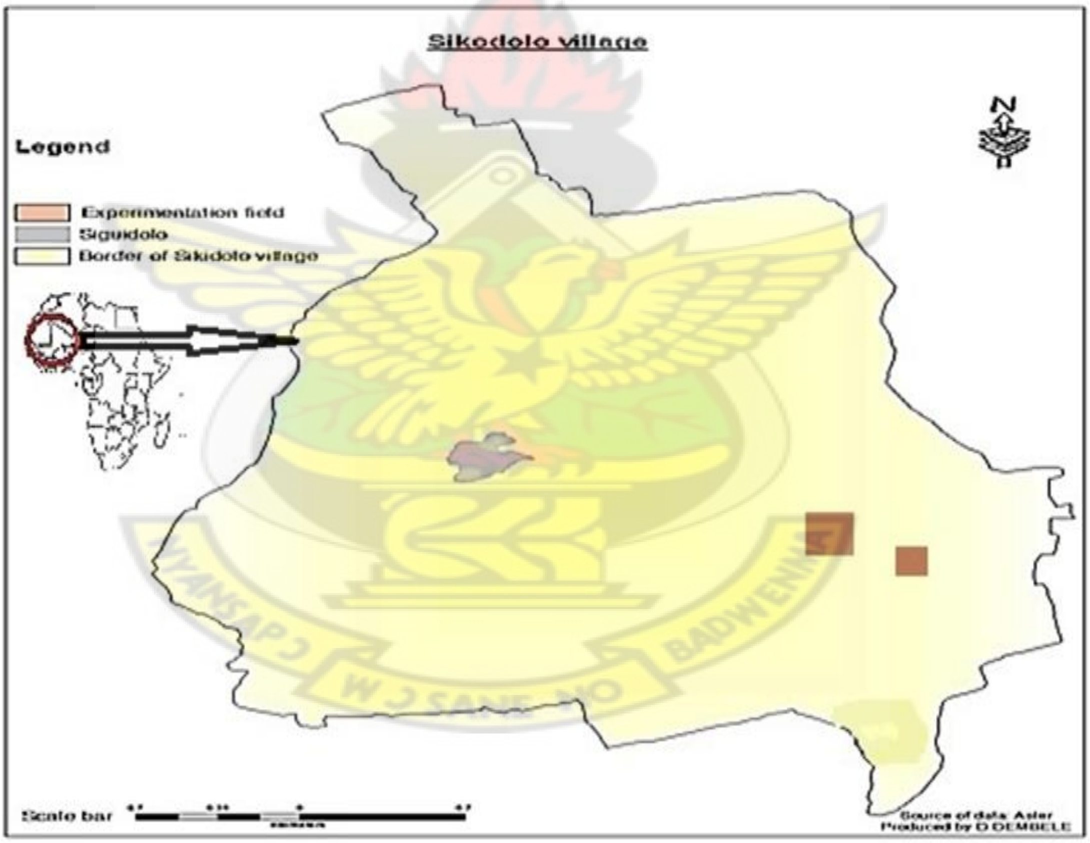
A number of modified tillage practices have been developed for providing a better soil and water - plant relations, reducing runoff as well as soil erosion by enhancing infiltration capacity of the soil. Tillage depth and intensity with hand tools are very limited, but as they also leaves the soil exposed and equally lead to soil degradation and erosion. Hoeing for land preparation is eliminated with conservation agriculture (CA), and with the major labour bottleneck in the cropping season. Non-overturning hoeing tillage largely diminishes soil downslope translocation and results in a significant reduction in tillage erosion. Contour ridges sometimes called contour furrows or micro watersheds, are used for crop production. Contour ridges are some of the simplest and cheapest methods of water harvesting. It can be implemented by the farmer using a hoe, at no or little extra cost. External support is limited to a minimum, alternatively it can be mechanized and a variety of implements can be used. Chemical fertilizers are used in intensive agriculture to correct known plant-nutrient deficiencies to provide high levels of nutrition, which aid plants in withstanding stress conditions; to maintain optimum soil fertility conditions; and to improve crop quality. Adequate fertilization programs supply the amounts of plant nutrients needed to sustain maximum net returns. The application of high soil organic manure rates have been proved to enhance the yield components of cereals as well as soil aeration, soil density and maximize water holding capacity of soil for seed germination and plant root development. Lime is usually added to acid soils to increase soil pH. The addition of lime not does only replace hydrogen ions and raises soil pH, thereby eliminating most major problems associated with acid soils but it also provides two nutrients, calcium and magnesium to the soil. Lime also makes phosphorus that is added to the soil more available for plant growth and increases the availability of nitrogen by hastening the decomposition of organic matter. Liming materials are relatively inexpensive, comparatively mild to handle and leave no objectionable residues in the soil. As soil acidification occurs, soil chemical and biological properties change. One chemical change is increased solubility of aluminum (Al) and manganese (Mn), both of which can be toxic to plants. The combined application of organic and mineral nutrient sources may lead to synergistic, antagonistic or additive effects on crop production.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1. Study site

The study was conducted **at** Sikidolo (Konobougou) in the Sahelian Zone of Mali. The experimental site, is characterized by lateritic uplands alternating with gentle slopes and lowlands, in which rainfall ranges from 600 to 800 mm (Kablan *et al.*, 2008). The topography of the region is dominated by flat surfaces with an average altitude of about 300 m and hills that seldom exceed 400 m in altitude.



Source: MDRI 1998 Realization: October 2014 Auteur: Dembele

Figure 3.1: Location of study site (Sikidolo village)

3.1.1 Soil

Some chemical and physical properties of the soil and manure used for the study are presented in Table 3.1 and 3.2. Landon's (1991) guidelines were used to interpret the result of the soil analysis. The soil under the millet and sorghum is loamy sand classified as Ultisols (FAO, 2006). The pH of the soil under the millet was very strongly acidic whereas that under the sorghum was moderately acidic (Table 3.1). The amount of organic carbon, nitrogen and phosphorus content of the soil under both crops was low with very low effective cation exchange capacity (ECEC) (Table 3.1). The fertility and productivity status of the soil will therefore be enhanced by the addition of soil amendments. Farmers (in Mali) often rotate sorghum and millet or occasionally maize with cotton to take advantage of the residual fertilizer effects (Kablan *et al.*, 2008).

Using the guidelines of Odedina (2014), the level of nitrogen, phosphorus and potassium content of the manure are considered to be high (Table 3.2). It was therefore a rich source of nutrients. The presence of micro nutrients (Fe, Zn and Cu) represented another useful quality of the compost. The C/N ratio of the compost was slightly higher than the level recommended for a high quality organic material (Table 3.2). According to Myers *et al.* (1994), decomposition of materials with C/N ratio < 25 easily release mineral N. With an N content of 1.73 % (which is greater than the soil's N), the compost could potentially release N to enhance the low N status of the soil for improved crop growth.

Table 3.1: Initial physical and chemical properties of the soil used for millet and sorghum cultivation

Parameters	Millet		Sorghum	
	CR	HT	CR	HT
pH (1:1, H_2O)	4.68	4.83	5.94	5.57
Organic Carbon (%)	0.35	0.41	0.43	0.41
Total N (%)	0.02	0.02	0.03	0.03
Available P (mg kg^{-1})	7.90	9.30	7.53	4.10
Exchangeable K ($cmol_c$ kg^{-1})	0.10	0.12	0.20	0.14
Exchangeable Ca ($cmol_c$ kg^{-1})	0.84	1.18	2.41	1.74
Exchangeable Mg ($cmol_c$ kg^{-1})	0.48	0.63	1.20	0.95
Exchangeable Na ($cmol_c$ kg^{-1})	0.06	0.05	0.08	0.07
ECEC ($cmol_c$ kg^{-1})	1.50	2.00	3.89	2.90
Sand (%)	79.2	81.73	70.64	76.53
Silt (%)	18.33	15.47	24.36	19.20
Clay (%)	2.40	2.80	5.14	4.20

Table 3.2: Chemical analysis of manure nutrient content

Nutrients	Nutrient content
Dry matter content (%)	51.00
Total N (%)	1.73
Total P (%)	0.40
Total K (%)	1.05
Carbon (C %)	47.73
C/N	27.59
Calcium (%)	0.04
Magnesium (%)	0.29
Fe (mg kg^{-1})	120.47
Zn (mg kg^{-1})	46.90
Cu (mg kg^{-1})	2.44

3.2 Experimental Design

Two experiments were conducted using millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor L. Moench*) as test crops. Each trial was a factorial combination of two tillage practices (Contour ridges and hoe tillage) and five types of soil amendments (1- No amendment, 2- Manure, 3- Manure + Urea, 4- Manure + Urea + RP (rock phosphate), 5- Manure+ Urea + Lime) in a randomized complete block design with three replications. Tillage practices conducted the main plots with the soil amendments as subplots. The dimension of the subplots were 4 x 5m. The main plots were separated by 1m wide access. The levels of soil amendments applied are presented in Table 3.3.

Table 3.3: Soil amendments applied on millet fields

Soil amendments	Amount of manure ($Mg\ ha^{-1}$)	Urea ($kg\ ha^{-1}$)	RP ($kg\ ha^{-1}$)	Lime ($kg\ ha^{-1}$)
No amendment	0			
Manure	5			
Manure + Urea	5	50		
Manure + Urea + RP	5	50	100	
Manure + Urea + Lime	5	50		750

The amount of urea applied to sorghum was 100 kg ha^{-1}

3.3 Land preparation

Animal drawn mould board ploughs and tine harrows were used to prepare the contour ridges plots for seeding. The other plots were subjected to hoe tillage as the prevalent local tillage.

The variety of millet planted was Toronio and that of sorghum was CSM63E, locally called Jakumbe which is an improved sorghum variety. The spacing of both millet and sorghum was 50 x 71 cm.

3.4 Crop management

Weeds on the fields were controlled by hoeing at 15 days and 30 days after planting (DAP). Animal drawn mould board ploughs and tine harrows were used for earthing up after 40 days. Grain yield, and plant growth were determined from the central three rows. Samples of yield components (stem, grain, and leaves) were collected.

3.5 Application of soil amendments

The organic manure (Sabugnuma) used for the study was obtained from the Industry of Production of Bacterial Fertilizers (PROFEBA). The natural phosphorus of Tilemsi (PNT) was bought at the commercial society of Seydou Nantoume. Farmyard manure, rock phosphate, and lime were mixed thoroughly, weighed for each plot, spread evenly, and incorporated into the soil before planting. The application of N as urea was incorporated into ridges 15 days and 30 days after planting.

3.6 Soil sampling and laboratory analysis

A composite of five soil samples were collected before planting and after harvest and analyzed for their chemical and physical properties

3.6.1 Soil texture determination

Particle size analysis was done by the hydrometer method (Anderson and Ingram, 1993). Fifty grammes g of air dried soil was weighed into a conical flask and a dispersing agent sodium hexa mega phosphate added. After shaking on a reciprocal shaker at 400 r.p.m for 18 hours, the samples were transferred to sedimentation cylinders and topped up with distilled water to make up to the 1000ml mark. A hydrometer was used to measure the density of the suspension of soil and water at 40 seconds and 3 hours and a thermometer used to measure the temperature at each reading.

Calculation

$\%\ \text{Sand} = 100 - \{H1 - 0.2 \times (T1 - 20) - 2.0\} \times 2$,

$\%\ \text{Clay} = \{H2 + 0.2 \times (T2 - 20) - 2.0\} \times 2$

% Silt= 100- (%Sand+% Clay)

Where H1 is first hydrometer reading, H2 is second hydrometer reading, T1 is temperature of suspension at first hydrometer reading, and T2 is temperature of suspension at second hydrometer reading.

3.6.2 Soil pH

Soil pH was determined by the McLean (1982) method. A 10 g of the soil sample in a 50 ml beaker was mixed with 10 ml of distilled water, stirred for five minutes and allowed to stand for 30 minutes. A pH meter (Eutech Instruments pH 510) zeroed by putting its glass electrode into distilled water was used to take the pH of the suspended solution at a temperature of 26.9^o C.

3.6.3 Soil organic carbon

Soil organic C was determined by the modified Walkley-Black wet oxidation method as outlined by Nelson and Sommers (1982). Two grams (2.00 g) of soil was weighed into 500 ml conical flask and 10 ml of 0.166 *M* (1.0 *N*) $K_2Cr_2O_7$ solution added, followed by 20 ml concentration. H_2SO_4 and allowed to cool on an asbestos sheet for 30 minutes. Two hundred milliliters of distilled water was added followed by 10 ml of H_3PO_4 and then 1.0 ml of diphenylamine indicator solution. This mixture was then titrated with 1.0 *M* ferrous sulphate solution until the colour changed from a blue-black colouration to a permanent greenish colour. A blank determination was carried out in a similar fashion in every batch of samples analysed without soil.

Calculation:

$$\%C = \frac{N \times \langle V_{bl} - V_s \rangle \times 0 \cdot 003 \times 1 \cdot 33 \times 100}{g}$$

Where;

N =Normality of $FeSO_4$ solution; V_{bl} = ml of $FeSO_4$ used for blank titration; V_s = ml of $FeSO_4$ used for sample titration; g = mass of soil taken in gram; 0.003= milli-equivalent weight of C in grams (12/4000);

1.33 = correction factor used to convert the Wet combustion C value to the true C value since the Wet combustion method is about 75 % efficient in estimating C value , (i.e. 100/75 = 1.33).

Organic matter content was determined using the formula:

% C X 1.724. (1.724 is the Conventional Van Bemellen factor)

3.6.4 Total Nitrogen

Total nitrogen was determined by the modified Kjeldahl digestion method (Bremner and Mulvaney, 1982). A 10 g soil was weighed into a 250 ml Kjeldahl digestion flask and 10 ml of distilled water were added to it. Ten milliliters of concentrated H_2SO_4 was added followed by addition of one tablet of selenium and potassium sulphate mixture and 0.10 g of salicylic acid. The mixture was made to stand for 30 minutes and heated mildly to convert any nitrates and nitrites into ammonium compounds. The mixture was then heated more strongly (300 to 350 ^oC) to digest the soil to a permanent clear colour. The digest was cooled and transferred to a 100 ml volumetric flask and made up to the mark with distilled water. A 20 ml aliquot of the solution was transferred into a tecatar apparatus allowed to flow into the flask. The distilled ammonium was collected into a 10 ml boric acid, bromocerol green and methyl red solution. The distillate was titrated with 0.01 M HCl solution. A blank digestion, distillation and titration were also carried out as a check against traces of nitrogen in the reagents and water used.

$$\% N = \frac{(a - b) \times 1.4 \times M \times V}{s \times t}$$

Where

a = ml HCl used for sample titration,

b = ml HCl used for blank titration,

M = molarity of HCl,

V = total volume of digest,

s = weight of soil taken for digestion in grains,

t = volume of aliquot taken for distillation, and 1.4 = 14 X 10^{-3} X 100 % (14 is the atomic weight of N).

3.6.5 Available Phosphorus

Available phosphorus was determined by the Bray P1- method (Bray and Kurtz, 1945). A 2 g of soil sample was extracted with 20 ml of Bray P1 solution (0.03 M NH_4F and 0.025 M HCl). The mixture was shaken on a Stuart reciprocal shaker for 1 minute and immediately filtered through Whatman no. 42 filter paper. A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6.0 was prepared by pipetting respectively mg P/l 0, 10, 20, 30, 40, 50 ml of 12 mg P l^{-1} into 100 ml volumetric flask and made up to the mark with distilled water. Phosphorus in the sample was determined on a pye-unicam spectrophotometer at a wavelength of 660 nm by the blue ammonium molybdate method with ascorbic acid as the reducing agent.

Calculation

$$\text{P (mk/kg)} = \frac{\text{(a - b) x Vs x df}}{\text{g}}$$

Where a is mgP/L in sample extract, b is mgP/L in blank, df is dilution factor, Vs is the volume of extract, and g is sample weight in grams.

3.6.6 Available potassium

Available potassium was determined by the method of Sparks *et al.* (1996). Extraction with 0. 1M HCl gives an indication of K in the soil in soluble form, the complex K and the absorbent part of the minerals in the set K. This could be done by the addition of HCl, or by introduction of oxalic acid. By further addition of HCl probably more K would be extracted. This is due to more rapid destruction of minerals by the higher initial acidity. By addition of oxalic acid concentration in H^+ ion remains constant during the extraction and Ca dissolved $CaCO_3$ precipitates as Ca-oxalate.

Calculation

K in mg/100 g soil = (a-b), K_2O in mg/100g soil = 1.2 (a-b), Or a K = ppm measured for sample, b = K ppm measured for blank.

3.6.7 Determination of exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 M ammonium acetate (NH_4OAc) extract as described by Black (1986) whilst the exchangeable acidity (hydrogen and aluminum) was determined in 1.0 M KCL extract as described by Page *et al*. (1982).

3.6.7.1 Extraction of the exchangeable bases

A 5 g sample was transferred into a leaching tube and leached with 100 ml of buffered 1.0 M ammonium acetate (NH_4OAc) solution at pH 7.

3.6.7.2 Exchangeable calcium and magnesium

Calcium and Magnesium were determined by method of Thomas (1982). For the determination of the calcium plus magnesium, a 25 ml of the extract was transferred into an Erlenmeyer flask. A 1.0 ml portion of hydroxylamine hydrochloride, 1.0 ml of 2.0 per cent potassium cyanide buffer (from a burette), 1.0 ml of 2.0 per cent potassium ferrocyanide, 10.0 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution were added. The solution was titrated with 0.01 M EDTA (ethylene diamine tetraacetic acid) to a pure turquoise blue colour. A 20 ml 0.01 M magnesium chloride solution was also titrated with 0.01 M EDTA in the presence of 25 ml of 1.0 M ammonium acetate solution to provide a standard blue colour for the titration.

3.6.7.3 Exchangeable potassium and sodium

Exchangeable potassium and sodium were determined by method of Thomas (1982). Determination of potassium and sodium in the percolate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg/l potassium and sodium solutions to 100 mg l^{-1}. This was done by taking a 25 ml portion of each into one 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15, and 20 ml of the 100 mg l^{-1} standard solution were put into 200 ml volumetric flasks respectively. One hundred milliliters of 1.0 M NH_4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg l^{-1} potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 766.5 and 589.0 nm, respectively.

Calculations

$$\text{Exchangeable K (cmol kg}^{-1}\text{ soil)} = \frac{\text{(a - b) x 250 x mcf}}{\text{10 x 39.1 x s}}$$

$$\text{Exchangeable Na (cmol kg}^{-1}\text{ soil)} = \frac{\text{(a - b) x 250 x mcf}}{\text{10 x 23 x s}}$$

Where a is mg l^{-1} K or Na in the diluted sample percolate, b is mg l^{-1} K or Na in the diluted blank percolate, s is air-dried sample weight of soil in gramme, and mcf is moisture correcting factor.

3.6.7.4 Exchangeable acidity:

Exchangeable acidity was determined by by method of Thomas (1982). Exchangeable acidity is defined as the sum of Al and H. The soil sample was extracted with unbuffered 1.0 M KCl, and the Al and H was determined by titration. Ten grams of soil sample was put in a 100 ml bottle and 50 ml of 1. 0 M KCl solution added. The bottle was capped and shaken for 1. 0 hour and then filtered. Twenty five milliliters portion of the filtrate was taken with a pipette into a 250 ml Erlenmeyer flask and 2-3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1 M NaOH until the colour just turned permanently pink. A blank was included in the titration.

Calculation

$$\text{Exchangeab le acidity (cmol/kg soil)} = \frac{\text{(a - b) x M x 2 x 100 x mcf}}{\text{s}}$$

Where a is ml NaOH used to titrate with sample, b is ml NaOH used to titrate with blank, M is molarity of NaOH solution, s is air dried soil sample weight in gram, 2 is 50/25 (filtrate / pipetted volume), and mcf is moisture correction factor [(100 + % moisture) / 100].

3.6.8 Effective cation exchange capacity (ECEC)

Effective cation exchange capacity was determined by the sum of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and exchangeable acidity (Al^{3+} + H^+).

3.7 Laboratory analysis of plant and manure used

3.7.1 Total nitrogen

Total N was determined using the Kjeldahl digestion method as described by Okalabo *et al*. (1993). Two (2.0) grams of plant material oven dried and ground to pass through a 0.5 mm sieve was weighed into a 500 ml Kjeldahl digestion flask and one spatula of catalyst (copper sulphate + sodium sulphate + selenium powder mixture) followed by 20 ml of concentrated H_2SO_4 was added. The mixture was heated strongly to digest the plant material to a permanent clear green colour. The digest was cooled and transferred to a 100 ml volumetric flask and made up to the mark with distilled water. A 10 ml aliquot of the digest was transferred into a Tecator distillation flask and 20 ml of 40 % NaOH solution was added. Steam from a Foss Tecator apparatus was allowed to flow into the flask. The ammonium distilled was collected into a 250 ml flask containing 15 ml of 4 % boric acid with mixed indicator of bromocresol green and methyl red. The distillate was titrated with 0.1 N HCl solution. A blank digestion, distillation and titration were carried out as a check against traces of nitrogen in the reagents and water used.

Calculation: $\% N = \frac{(a-b) \times 1 \cdot 4 \times N \times V}{s \times t}$

Where;

a = ml HCl used for sample titration; b = ml HCl used for blank titration; 1.4 = 14 x 10-3 x 100 % (14 = atomic weight of N); N= normality of HCl; V = total volume of digest; S = mass of oven dry plant sample taken for digestion in grams (2.0 g); t = volume of aliquot taken for distillation (10.0 ml)

3.7.2 Total phosphorus

A 5 ml aliquot of the supernatant digest was pipetted into a 50 ml volumetric flask. Five (5.0) millilitres of ammonium molybdate – ammonium vanadate solution was added. The volume of the mixture was made up with distilled water to the 50 ml mark and allowed to stand undisturbed for 30 minutes for colour development. Standard curve was developed concurrently with P concentrations ranging from 0.0, 5.0, 10.0, 15.0, 20.0 mg P / kg. The absorbance of blank, control and the samples were read on the Jenway Colorimeter at a wavelength of 430 nm.

A graph of absorbance verse concentration (ppm) P was plotted. The blank and unknown standards were read and the ppm P was obtained by interpolation on the graph plotted from which P concentrations were determined.

Calculation:

P content (μg) in 1.0 g of plant sample = C x df

P content (g) in 100 g plant sample, (% P) = $\frac{\mathrm{C \times df \times 100}}{1000000} = \frac{\mathrm{C}}{10}$

Where;

C = concentration of P (μg ml^{-1}) as read from the standard curve

df = dilution factor, which is 100 x10 = 1000, calculated as :

- 1.0 g of sample made up to 100 ml (100 times)
- 5.0 ml of sample solution made up to 50 ml (10 times)
- 1000 000 = factor for converting μg to g.

3.7.3 Determination of K, Na, Ca, Zn, Cu, Fe and Mg

One (1.0) gram of plant sample was weighed into a clean ceramic crucible. An empty crucible was included for a blank in each batch of 24 samples. The samples were arranged in a cool muffle furnace and temperature ramped to 500 ^{o}c over a period of 2 hours. This temperature was allowed to remain for an additional 2 hours. The samples were allowed to cool down in the oven.

Samples were then removed from the oven ensuring that the environment is free from breeze. Ashed samples were transferred first into already numbered 50 ml centrifuge tubes. Crucibles were rinsed with 10 ml of distilled water into the centrifuge tubes. More rinsing of the crucible with 10 ml of aqua regia was done. The samples were shaken for 5 minutes for proper mixing on a mechanical reciprocating shaker. Samples were centrifuged for 10 minutes at 3000 rpm and then transferred into 100 ml volumetric flask and again made up to the 100 ml mark. The clear supernatant digest were decanted into clean reagent bottles for macro- and micro-nutrients determination.

This procedure was used for the analysis of Ca, Mg, K, Na, Zn, Cu and Fe. These nutrient elements were determined using flame atomic absorption spectrophotometer model VGB 210 from Buck Scientific USA.

3.8 Determination of growth and yield parameters

Seedling emergence was determined by counting the emerged seedling per hill four days after sowing. Plant height at maturity was measured with a graduated rule.

Grain yield: Plant samples per 4.29 m^2 in each plot were harvested in the middle of each treatment plot leaving the border rows. The grains were sun dried and their weight were measured and extrapolated on a hectare basis.

Biomass yield: the shoot biomass of the crops were also sun dried and weighed after the removal of the grain.

3.9 Calculations

3.9.1 Total N

Total N in the straw and grain samples were used to calculate N use efficiency (NUE) and its component traits according to an expanded model of Moll *et al.* (1982).

$$\mathrm{NUE} = \frac{\mathrm{Ntf - Ntc}}{\mathrm{Ns}} \times 100$$

Where, Ntf (kg ha^{-1}) = total above-ground N content at maturity of fertilized treatment, Ntc (kg ha^{-1}) = total above-ground N content at maturity of control treatment, Ns (kg ha^{-1}) = N supplied.

3.9.2 Value to cost ratio (VCR)

The unsubsidized input costs and the crop peak prices were used to calculate the VCR as a first indicator of acceptability of investment, using the formula of Nziguheba *et al.* (2010): VCR $= \frac{Y-Yc}{X}$

Where Y is the value of the crop in intervention plots, Yc is the value of the crop harvested in control plots, and X is the cost of inputs (seeds and fertilizers).

3.10 Statistical analysis

Data was subjected to analysis of variance using GENSTAT version 12 (GenStat Release 12.1 (PC/Windows Vista) Copyright (2009), VSN International Ltd) and significant means were separated with least significant difference (Lsd) at 5% and correlation analysis.

CHAPTER FOUR

4.0 RESULTS

4.1 The effect of tillage practice and soil amendments on soil chemical properties

The results of the impact of tillage and soil amendments on soil chemical properties are presented in Table 4.1 and 4.2. Soil pH and exchangeable K under both millet and sorghum were not significantly influenced by tillage. However, the contour ridge significantly ($p<0.05$) recorded higher organic carbon and available P than the hoe tillage under millet. The difference in the OC of the two tillage practices under sorghum was not significant ($p<0.05$). In general OC content of the soil was low.

Soil amendment significantly ($p<0.05$) affected soil pH under both millet and sorghum. Soil pH ranged from 4.92 to 5.07 and 4.83 to 5.03 under millet and sorghum respectively. The pH under millet ranked as Manure + Urea > Manure + Urea + RP > No amendment > Manure + Urea + Lime > Manure. Significant differences ($p<0.05$) in pH were observed between Manure + Urea and that of Manure + Urea and Manure + Urea + RP where the very strongly acidic condition under the manure was improved to strongly acid by the latter two amendments. Manure + Urea also recorded significantly ($p<0.05$) higher pH than the no amendment.

Table 4.1: Main effect of soil amendment and tillage practice on soil pH and organic carbon

	pH		Organic carbon (%)	
Soil amendments	Millet	Sorghum	Millet	Sorghum
No amendment	4.93	4.83	0.38	0.32
Manure	4.87	4.90	0.32	0.39
Manure + Urea	5.07	5.00	0.37	0.41
Manure + Urea + RP	5.02	5.03	0.37	0.31
Manure + Urea + Lime	4.92	4.95	0.35	0.35
F.pr (soil amendments)	0.02	0.09	0.96	0.63
L.s.d (0.05)	0.12	0.15	0.16	0.17
Tillage practice				
Contour ridge	4.96	4.95	0.43	0.38
Hoe tillage	4.96	4.94	0.29	0.33
F.pr (tillage practices)	1.00	0.89	0.01	0.29
Fpr (Soil amendment x Tillage)	0.08	0.15	0.86	0.10
L.s.d (0.05)	0.08	0.10	0.10	0.11
CV (%)	2.00	2.60	37.40	38.60

RP: rock phosphate

Organic carbon and available P under both millet and sorghum and exchangeable K under millet were not significantly ($p<0.05$) impacted upon by soil amendments (Table 4.1 and 4.2). However, Manure + Urea + RP recorded significantly higher exchangeable K than no amendment for sorghum. The differences between the remaining amendments under the sorghum were not significant (Table 4.2).

The tillage x amendment interaction did not significantly affect the chemical properties of the soil (Table 4.1 and 4.2).

Table 4.2: Main effect of soil amendment and tillage practice on exchangeable potassium and available phosphorus

	Exchangeable K ($cmol_c$ kg^{-1})		Available P (mg kg^{-1})	
Soil amendments	Millet	Sorghum	Millet	Sorghum
No amendment	0.16	0.10	1.20	1.25
Manure	0.16	0.13	1.56	2.16
Manure + Urea	0.17	0.13	1.50	1.21
Manure + Urea + RP	0.18	0.15	1.50	1.04
Manure + Urea + Lime	0.18	0.13	1.91	1.22
F.pr (soil amendments)	0.92	0.19	0.58	0.63
L.s.d (0.05)	0.07	0.04	1.25	1.69
Tillage practice				
Contour ridge	0.15	0.13	1.82	1.11
Hoe tillage	0.18	0.12	1.25	1.64
F.pr (tillage practices)	0.24	0.22	0.05	0.29
Fpr (Soil amendment x Tillage)	0.44	0.75	0.90	0.90
L.s.d (0.05)	0.04	0.02	1.25	1.07
CV (%)	32.20	24.80	47.5	97.60

RP: rock phosphate

4.2 The effect of tillage practice and soil amendments on plants height and biomass

Plant height was used as proxy for growth. The mean height attained at the end of the experiment as affected by tillage and soil amendments is presented in Table 4.3. Plant height ranged from 1.76 to 1.98 m for millet under hoe tillage and contour ridge. The difference was significant ($p<0.05$). Plant height of millet under the different soil amendments ranged between 1.20 and 2.08 m in a decreasing order of Manure + Urea + RP > Manure + Urea = Manure + Urea + lime > Manure > no amendment. The differences in plant height among all the amendments were not significant but however they all had significantly ($p<0.05$) greater height than no amendment.

In the case of sorghum, plant height ranging from 2.35 to 2.56 m, was not significantly ($p<0.05$) affected by tillage practices (Table 4.3). Soil amendments, on the other hand, effected significant ($p<0.05$) differences in plant height with values ranging from 1.40 to 2.81 m in the order of Manure + Urea Lime > Manure > Manure + Urea > Manure + Urea + RP > no amendment. As observed in the case of tillage, plant height was not significantly affected by soil amendments but they all had greater height than no amendment.

The results presented in Table 4.3 showed tillage to significantly ($p<0.05$) affect the biomass yield of millet but not that of sorghum. On the other hand, soil amendments significantly ($p<0.050$ influenced biomass yield of both millet and sorghum. Biomass yield of millet ranged from 1942 to 8508 kg ha^{-1} in decreasing trend of Manure + Urea + lime > Manure + Urea > Manure + Urea + RP > no amendment. All the amendments produced significantly ($p<0.05$) more biomass than the no amendment. Apart from the significant difference in biomass yield between the Manure and

Manure + Urea + Lime the remaining amendments did not differ significantly in the biomass yield. The biomass yield of sorghum , on the other hand, ranged from 5594 to 17995 kg ha^{-1} in the order of Manure + Urea + RP > Manure + Urea > Manure + Urea + Lime > Manure > no amendment. The soil amendments did not significantly affect biomass yield. However, all of them significantly out yielded no amendment in biomass yield. Tillage x amendment interactions significantly affected biomass yield of millet but not that of sorghum (Table 4.4).

Table 4.3: Main effect of tillage practice and soil amendment on plants growth

	Biomass yield (kg ha^{-1})		Plant height (m)	
Soil amendments	Millet	Sorghum	Millet	Sorghum
No amendment	1942	5594	1.20	1.40
Manure	5789	14639	1.93	2.72
Manure + Urea	7692	17529	2.07	2.70
Manure + Urea + RP	6566	17995	2.08	2.64
Manure + Urea + Lime	8508	17343	2.07	2.81
Fpr (soil amendment)	<.001	<.001	<.001	<.001
L.s.d (0.05)	2410.7	3538.8	0.32	0.36
Tillage practice				
Contour ridge	7599	14583	1.98	2.56
Hoe tillage	4600	14657	1.76	2.35
Fpr (Tillage practice)	<.001	0.945	0.04	0.08
L.s.d (0.05)	1524.7	2238.1	0.21	0.23
Fpr (soil amendment x Tillage)	0.03	0.67	0.67	0.62
CV (%)	32.6	20.0	14.3	12.2

Table 4.4 Mean results of the tillage x amendment interaction on millet biomass yield

Soil amendments	CR	HT
No amendment	1632	2253
Manure	6605	4973
Manure + Urea	9402	5983
Manure + Urea + RP	8003	5128
Manure + Urea + Lime	12354	4662
Fpr (Soil amendment x Tillage)	0.027	
L.s.d (0.05)	1524.7	
CV (%)	32.6	

4.3 The impact of tillage and soil amendments on grain yield

The mean grain yield as impacted upon by tillage and soil amendments is presented in Table 4.5. Tillage had no significant ($p<0.05$) effect on the grain yields of both millet and sorghum. Grain yield ranged between 777 and 870 and 179 and 288 kg ha^{-1} for millet and sorghum respectively. Through not significant the contour ridge produced relatively higher grain yield than hoe tillage in both millet and sorghum. The percentage increase was 11 % and 38 % in millet and sorghum respectively.

Grain yield in millet as affected by soil amendments ranged from 311 to 1321 kg ha^{-1} for millet and in a decreasing order of Manure + Urea + Lime > Manure + Urea > Manure + Urea + RP > Manure > no amendment. All amendments produced significantly ($p<0.05$) greater grain yield than no amendment. The differences in grain yield for Manure + Urea and Manure + Urea + RP were however not significant.

In sorghum, grain yield varied from 55 to 372 kg ha^{-1}, with a decreasing trend of Manure > Manure + Urea > Manure + Urea + lime > Manure + Urea + RP > no amendment (Table 4.5). Whilst the differences between all the amendments were not significant, they all outyielded no amendment significantly ($p<0.05$) (Table 4.5). Tillage x soil amendments, however had no significant effect ($p<0.05$) on grain yield (Table 4.5).

Table 4.5: Main effect of soil amendment and tillage practice on grain yield

Soil amendments	Grain yield (kg ha^{-1})	
	Millet	Sorghum
No amendment	311	55
Manure	660	372
Manure +Urea	932	335
Manure + Urea + RP	894	199
Manure + Urea + Lime	1321	206
Fpr (soil amendment)	<.001	0.013
L.s.d (0.05)	322.4	179.6
Tillage practice		
Contour ridge	870	288
Hoe tillage	777	179
Fpr (Tillage practice)	0.349	0.059
L.s.d (0.05)	203.9	113.6
Fpr (Soil amendment x Tillage)	0.211	0.306
CV (%)	32.3	63.4

4.4 The effect of tillage and soil amendments on nitrogen use efficiency (NUE)

Nitrogen use efficiency by millet (Table 4.6) was significantly ($p<0.05$) affected by tillage but not soil amendments. Nitrogen use efficiency was greater under CR than HT. Nitrogen use efficiency was also significantly influenced by tillage x amendment interaction. The contour ridge x Manure + Urea + lime gave the highest (102) NUE whilst the hoe tillage x Manure + Urea + RP recorded the least (15) NUE (Table 4.7).

Table 4.6: Main effect of soil amendment and tillage practice on NUE of millet

Soil amendments	NUE of millet
No amendment	
Manure	40
Manure + Urea	53
Manure + Urea + RP	43
Manure + Urea + Lime	61
F.pr (soil amendments)	0.40
L.s.d (0.05)	28.40
Tillage practice	
Contour ridge	79
Hoe tillage	19
F.pr (tillage practices)	<.001
Fpr (Soil amendment x Tillage)	0.05
L.s.d (0.05)	17.9
CV (%)	46.6

Table 4.7 Mean results of the tillage x amendment interaction on NUE of millet

Soil amendments	CR	HT
No amendment	80	18
Manure	60	20
Manure + Urea	84	22
Manure + Urea + RP	71	15
Manure + Urea + Lime	102	20
Fpr (Soil amendment X Tillage)	0.05	
L.s.d (0.05)	17.9	
CV (%)	46.6	

4.5 Relationship between grain yields, N applied and, soil chemical properties under millet and sorghum cultivation

Table 4.8 and Table 4.9 show the relationship among grain yield, N applied, soil pH, organic carbon, total N, available P and exchangeable K and NUE in the sorghum and millet cropping system at the experimental sites. Significant positive relationships were recorded between grain yield and the amount of N applied (r = 0.78), between total N and soil pH (r = 0.76) and also between NUE and OC (r = 0.93) in the millet cropping system (Table 4.8).

Significant positive relationships were recorded between the amount of N applied and pH (r = 0.68) and also between exchangeable K and pH (r = 0.82) in the sorghum cropping system. There were no significant correlations among the other parameters measured (Table 4.9).

Table 4.8: Correlation coefficient (r) showing the linear interrelationships among grain yield, N applied, NUE and selected soil parameters in a millet cropping system

	Grain yield	**N applied**	**pH**	**OC**	**Exch K**	**Avai P**	**Total N**	**NUE**
Grain yield	1							
N applied	0.78*	1						
pH	0.04^{NS}	0.52^{NS}	1					
OC	0.05^{NS}	0.09^{NS}	0.30^{NS}	1				
Exch K	0.04^{NS}	0.33^{NS}	-0.03^{NS}	-0.53^{NS}	1			
Avai P	-0.49^{NS}	-0.18^{NS}	0.16^{NS}	0.19^{NS}	0.34^{NS}	1		
Total N	-0.08^{NS}	0.29^{NS}	0.76*	0.21^{NS}	0.13^{NS}	0.56^{NS}	1	
NUE	0.20^{NS}	0.12^{NS}	0.08^{NS}	0.93*	-0.38^{NS}	0.13^{NS}	0.070^{NS}	1

NS = not significant, * represents significance at p = 0.05, OC = organic carbon, NUE = nitrogen use efficiency.

Table 4.9: Correlation coefficient (r) showing the linear interrelationships among grain yield, N applied and selected soil parameters in a sorghum cropping system

	Grain yield	N applied	pH	OC	Exch K	Avai P	Total N
Grain yield	1						
N applied	0.20^{NS}	1					
pH	0.36^{NS}	0.68*	1				
OC	0.51^{NS}	-0.001^{NS}	-0.29^{NS}	1			
Exch K	0.48^{NS}	0.62^{NS}	0.82*	0.02^{NS}	1		
Avai P	0.21^{NS}	-0.47^{NS}	-0.22^{NS}	-0.04^{NS}	-0.25^{NS}	1	
Total N	0.45^{NS}	0.41^{NS}	0.23^{NS}	0.60^{NS}	0.21^{NS}	-0.17^{NS}	1

NS = not significant, * represents significance at p = 0.05, OC = organic carbon

4.6 Effect of tillage practice and soil amendments on millet value cost ratio (VCR)

On the experimental field of millet under contour ridge, the application of manure had the highest VCR of 1.8 followed by the application of the Manure + Urea + RP with 1.7 and the lowest value of 0.7 was obtained with the application of Manure + Urea + Lime (Table 4.10). For the hoe tillage, the highest value was obtained by the application of Manure + Urea with 1.2 followed by the application of Manure + Urea + Lime with 0.7 and the lowest was 0.2 with the application of Manure (Table 4.10).

Contour ridge x amendment interaction also had high value of 1.52 relative to the hoe tillage x amendment with 1.30 (Table 4.10)

4.7 Effect of tillage practice and soil amendments on sorghum value cost ratio

Under the contour ridge system on sorghum field, the application of the Manure produced the highest VCR of 1 whilst the value due to the application of Manure + Urea was 0.8; the application of Manure + Urea + Lime had the lowest value of 0.1 (Table 4.11). With the hoe tillage the VCR of 0.8 was the highest value obtained by the application of Manure followed by 0.3 by the application of Manure + Urea and the lowest was 0.1 with the application of Manure + Urea + RP (Table 4.11). The sorghum planted on contour ridge field under amendment had the highest value of VCR of 0.51 relative to the hoe tillage 0.34 (Table 4.11)

Table 4.10: VCR of soil amendments and tillage in millet cultivation

Soil tillage	Soil amendment	Grain yield (kg ha^{-1})	Income from grain (CFA)	Cost of amendment (CFA)	VCR
CR	Control	233	34950	-	-
CR	Manure	855	128250	53000	1.8
CR	Manure + Urea	932	139800	68000	1.5
CR	Manure + Urea + RP	1088	163200	76000	1.7
CR	Manure + Urea + Lime	1243	186450	208625	0.7
HT	Control	388	58200	-	-
HT	Manure	466	69900	53000	0.2
HT	Manure + Urea	932	139800	68000	1.2
HT	Manure + Urea + RP	699	104850	76000	0.6
HT	Manure + Urea + Lime	1399	209850	208625	0.7
CR x Soil amendments		1029.5	154425	101406.3	1.52
HT x Soil amendments		874	131100	101406.3	1.30

***** 1 kg millet = 150 CFA

Table 4.11: VCR of soil amendments and tillage in sorghum cultivation

Soil tillage	Soil amendment	Grain yield (kg ha^{-1})	Income from grain (CFA)	Cost of amendment (CFA)	VCR
CR	Control	58	8700	-	-
CR	Manure	415	62250	53000	1
CR	Manure + Urea	509	76350	68000	0.8
CR	Manure + Urea + RP	239	35850	76000	0.3
CR	Manure + Urea + Lime	219	32850	208625	0.1
HT	Control	52	7800	-	-
HT	Manure	329	49350	53000	0.8
HT	Manure + Urea	241	36150	68000	0.3
HT	Manure + Urea + RP	160	24000	76000	0.2
HT	Manure + Urea + Lime	193	28950	208625	0.1
CR x Soil amendments		345.5	51825	101406.3	0.51
HT x Soil amendments		230.75	34612.5	101406.3	0.34

***** 1 kg sorghum = 150 CFA

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of soil amendments and tillage practices on soil chemical properties

In millet cultivation the application of manure and urea with or without rock phosphate significantly ($p \leq 0.05$) increased the pH relative to the no amendment and the application of Manure + Urea + Lime. In sorghum cultivation, the application of soil amendments had no significant effect ($p < 0.05$) on pH. Considering that lime was applied immediately after land preparation in this study, the short duration for lime activity may account for the lack of response observed in sorghum field. Ball (2010) observed that as water is required for lime to react with the soil, effects of a lime application are slower in dry soil and may require a year to be effective. The use of manure and mineral fertilizers had no significant effect on OC available P. The phosphorus in the organic manures mainly occurs in the organic form, which is released after mineralization for availability to crops.

Manures have the advantage of supplying essential plant nutrients either directly or indirectly by alleviating aluminum toxicity or by producing organic acids which complex with aluminum, thereby increasing nutrient availability (Nziguheba *et al.*, 1998). The impact of animal manure application on soil organic carbon stock changes is of interest for both agronomic and environmental purposes. Émilie and Denis (2013) quantified the response of SOC stocks to manure application from a large pool of individual studies and reported a dominant effect of cumulative manure input on SOC response which accounted for at least 53% of the variability in SOC stock.

The application of soil amendments had no significant ($p \leq 0.05$) effect on soil exchangeable potassium, although the application of manure with fertilizers led to high exchangeable K stock relative to application of manure alone. In a related study Ayeni and Adebinji (2010) found that addition of NPK fertilizer to poultry manure increased soil nutrients (organic carbon, N, P, K) more than the application of NPK or poultry manure alone even one year after their application.

The benefits of increased soil organic matter content in terms of crop yield and nutrient uptake have been demonstrated by the long-term experiments at Rothamsted (Johnston, 1986). In compost, K remains in water-soluble forms and thus does not need to be mineralized before becoming plant available. However, for the same reason it is at risk of leaching during the composting process and thus compost is often a poor source of K (Barker, 1997). Composting of organic wastes does not appear to affect K availability but application of both compost and mineral potassium may affect soil K (Baziramakenga *et al.*, 2001, Wen *et al.* 1997,). Compost made from grass and straw has been shown to contain approximately twice the K content of chicken manure (Eklind *et al.,* 1998). This type of material might therefore be beneficial in stockless organic systems. The application of soil amendments had no significant ($p<0.05$) effect on soil phosphorus although the application of RP together with urea and OM led to the highest available P. Gradual increase in soil phosphorus levels were more pronounced in rock phosphate treatment than control (Danso *et al.,* 2010). The increase in P availability observed through amendment of rock phosphate with organic materials may be attributed to the conversion of rock phosphate P to water-soluble form by the organic acids from the decomposition of manure (Khanna *et al.,* 1983)

Numerous studies confirmed the immediate effect of RP application on phosphorus availability in the soil (Adediran and Sobulo, 1997). However direct application of ground rock phosphate had been proved to be beneficial to crops on acids soils

(Nnadi and Haque, 1988), and may increase soil available P up to 115 % (Nnadi and Haque, 1988). The use of contour ridge had no significant effect on soil pH after millet and sorghum harvesting. The tillage practices had significant ($p \leq 0.05$) effect on soil organic carbon in millet cultivation. Contour ridge was evaluated in Mali, Senegal and Gambia to assess its potential impact on soil carbon sequestration, and was found to increase soil organic concentration after 3 years by 14% in Senegal (Doumbia *et al.*, 2009). It has been well documented that increased tillage intensities can reduce soil organic matter in the topsoil due to increased microbial activity and carbon (C) oxidation. The contour ridge increased soil organic carbon by 48.28 % under millet and by 15.15 % under sorghum. The tillage practices had no significant ($p \leq 0.05$) effect on the soil phosphorus, although the contour ridge increased available P of soils under millet cultivation by 38.7 %. Yusuf (2012) indicated, a number of investigators questioned the effectiveness of contour ridges in controlling surface runoff and soil erosion from smallholder farmers' fields. When compared with that in conventional management, sediment phosphorus loss from ridge furrow cultivation was significantly reduced by 37.29% while surface runoff total phosphorus loss was reduced by 34.62% (Xia *et al.*, 2014). Xia *et al.* (2014) reported that reduced tillage and contour ridge cultivation also effectively reduced phosphorus loss by reducing the amount of sediment because the ridge furrow system could retard runoff and increase the sedimentation in the furrows.

5.2. Effect of soil amendments and tillage on growth of millet and sorghum

The use of manure without other amendments significantly ($p < 0.05$) increased biomass yield of millet by 198.09 % and sorghum biomass yield by 161.69 % over that of no amendment. This observation supports the finding of Mpairwe *et al.* (2001) that the application of manure increased stover yield by 41.4 to 64.2 %. The quantity of manure applied was the minimum rate recommended for optimum crop production (Bationo and Mokwunye, 1991). The application of Manure produced significantly ($p < 0.05$) less biomass yield and plant height than the applications of Manure + Urea, Manure + Urea + RP, and Manure + Urea + Lime. Shahin *et al.* (2013) reported that green forage yield as well as dry forage yield was significantly affected by the interaction between nitrogen fertilization rates, where the highest yield was obtained with application of 60 –75 kg ha^{-1}.

Muhammad *et al.* (2009) reported that a significantly higher green forage (67.14 t ha^{-1}) and dry matter yield (19.83 t ha^{-1}) were obtained when nitrogen was applied at rate of 180 kg ha^{-1}. Increase in yield by nitrogen application has also been reported by Ayub *et al.* (2007). Khalid and Mohamed (2003) reported that the maximum fodder yield and dry matter yield was obtained by the application of 100 kg ha^{-1} of N and P. Roy and Khandaker (2010) reported that the biomass yield of sorghum was highest (26.16 MT ha^{-1}) and (25.58 MT ha^{-1}) under the application of TSP, these results were statistically not significant ($P<0.05$). At low rates, nitrogen fertilization increases forage yield with little effect on forage nitrogen (Blumenthal, 2008). It stimulates tiller development, increases leaf size, and lengthens the period of green leaves (Rhykerd and Noller, 1974). At a higher level of nitrogen fertilization, yield and nitrogen concentration in the forage are increased (Messman *et al.*, 1991).

The use of contour ridge significantly increased the plant height and biomass of both sorghum and millet. Contour ridge tillage increases soil nutrient and available soil moisture for crop uptake and enhanced crop growth (Li *et al.*, 2008). In a related study, Khlifi (2008) showed that dry matter yield in the CR plot was higher than that measured in the control.

5.3 Effect of soil amendments on grain yield of millet and sorghum

The application of Manure + Urea + Lime produced significantly ($P \leq 0.05$) higher grain yield than applications of Manure + Urea + PR, Manure + Urea and Manure. Adding lime increases soil pH, adds calcium and/or magnesium, and reduces the solubility of Al and Mn in the soil (Anderson *et al.,* 2013). Anderson *et al.* (2013) observed that lime mixed with 30 % or 100 % of total soil volume produced equivalent wheat yield.

The application of OM with or without inorganic fertilizers significantly ($P \leq 0.05$) enhanced grain yield than no amendment. The improvement in yield following manure application could be due to the improvement in soil fertility (Tabatabai and Dick, 1993). Kouyate *et al.* (2000) reported that incorporation of legumes as green manure at the end of the rainy season increased cereal grain yields by 27% - 37%, compared to cereal monoculture without organic amendment.

The application of manure with fertilizer had significant ($p \leq 0.05$) effect on millet grain yield relative to the application of Manure alone. Combined manure and inorganic fertilizers resulted in improved physical and chemical properties of the soil and increased millet production than the use of organic materials or inorganic fertilizer alone (Ngala *et al.,* 2012). Muhammad *et al.* (2009) reported that a significant increase in yield was recorded at each increased nitrogen level. Study conducted by Maman (2013) in Niger in 2004 through 2006 and indicated that application of 2 t ha^{-1} poultry manure increased pearl millet grain yield by 56 % whilst poultry manure plus 40 kg ha^{-1} of NPK 15-15-15 dry fertilizer increased grain yield by 117 %. In this study the application of Manure + Urea increased grain yield by 299.68 % whilst the application of Manure + Urea + RP increased it by 287.46 %. Kute and Chirchir (1994) reported that the results of two year study indicated that the combined application of inorganic and organic fertilizers application increased finger millet grain yields by more than a 1 t ha^{-1} and explained, why farmer preferred combined application of fertilizers and manures to no fertilizer in finger millet production. Okalebo *et al.* (1990) found that grain yield of millet increased significantly with the application of 135 kg P_2O_5 and 135 kg N ha^{-1}.

The use of tillage methods had no significant ($p \geq 0.05$) effect on millet and sorghum grain yield, although the use of contour ridge method increased grain yield of millet (11.97 %) and sorghum (60.89 %). Aina (2013) reported that tying ridges to permit more rainwater to infiltrate is an effective system in drier areas (< 1000 mm annual rainfall) on gentle slopes (< 7%). The annual rainfall at Konobougou was 589.5 mm and the steepness of the slope was 2 % for both millet and sorghum field. Contour ridge as a result of the increased infiltration of rainfall, increased water availability improving crop growth and reducing erosive runoff as shown in long-term studies initiated by Gigou *et al.* (2006) and soil water storage studies (Kablan *et al.*, 2008). These findings document increased soil water content resulting in increased crop yields. Yields may increase as much as 50 % for millet, sorghum, and maize (Gigou *et al.*, 2006). Traore *et al.,* (2004) reported that the effects of contour-ridges on millet yields have been variable, relative to the control the contour ridge increased millet grain yield in Mali by 27 % (1998), by 2 % (1999), and by 60 % in 2000. The observed improvement in grain yield following contour ridging is attributable to moisture conservation capacity of the tillage method. Soil moisture conservation is vital for smallholder cropping systems (Falkenmark *et al.*, 2001; Irshad *et al.*, 2007). The conserved moisture supplies water to the crop at the end of rainy season when plants are flowering and filling their grains

5.4 Effect of soil amendment and tillage practices on nitrogen use efficiency of millet

Tillage practices had significant ($p \leq 0.05$) effect on NUE of millet cropping system. The use of contour ridge significantly ($p \leq 0.05$) increased millet NUE by 315.8 % relative to the hoe tillage. Abdul *et al.* (2011) reported that NUE was also highest with ridge plantation, and indicated that this soil manipulation would have resulted in lower N losses (leaching), and while plant roots grow profusely to take up nutrients from a large soil volume. The application of Manure with or without inorganic fertilizers had no significant ($p < 0.05$) effect on millet NUE. Bationo *et al.* (2014) indicated the use of locally available phosphate rock, which could be an alternative to the use of high cost imported P fertilizers. Findings from this study have also shown the potential of RP for alleviating soil P limitations in the sandy soils.

5.5 Relationship between grain yield, N applied, and soil chemical properties under millet and sorghum cultivation

Millet NUE increased when N applied was increased. Increasing the N rate where lower rates are applied will increase crop production, especially in the developing world (Hardy and Havelka, 1975); however, if not combined with recommended management practices, this will decrease NUE. The progressive rise in N-accumulation is also corroborated by the upgraded capacity of N-use, by the yield enhancement in relation to the nutrient taken up by the crop and in the plant's ability to increase yield in response to N-supply. The total N correlated significantly with soil pH since the availability of nutrients is directly affected by soil pH. If the pH of the soil is too high or too low, some nutrients become insoluble. Perhaps increases in pH over the range measured in this study (4.83 to 5.03) was due to the fact that ammonification fungi actively release NH4 from the more recalcitrant components of the manure such as lignin and polyphenols and thereby increasing the total N. Similarly, significant positive relationship was recorded between the amount of N applied and soil pH under sorghum. Significant positive correlation between exchangeable K and pH implies increasing amount of exchangeable K as pH increases. This contributes to the enhancement of base saturation. Organic carbon also correlated significantly with NUE and this could be attributed to the fact that high amount of OM improves soil aggregation and reduce N losses through leaching and denitrification. As a result more N is made available for plant utilization.

5.6 Effect of tillage practice and soil amendments on millet and sorghum value cost ratio

It is reported that any treatment that had a VCR greater than 2 is profitable. Heerink (2005) stated that technically, VCR greater than 2 would imply profitability of fertilizer as long as other inputs were not altered as the use of fertilizer. Among the soil amendments, the sole manure gave the best profitability as indicated by its VCR value in the range of 1.8 under millet and 1 under sorghum. In spite of its contribution to increased crop yield, the manure is less costly than mineral fertilizers in Mali (10 FCFA kg^{-1}). The VCR for the remaining soil amendments were lower than that of sole manure because the prices of the component inorganic fertilizers are high. However, contrary results have been reported by several studies. Mkhabela (2003) reported higher financial benefits from supplementing manure with inorganic fertilizer relative to using sole manure. The application OM + Urea + Lime had the lowest value of VCR. The lime is extremely expensive in Mali and in the first year it is unable to reduce soil acidity in the dry area.

The use of CR showed the best value relative to the HT. In Mali, the making of CR is not expensive as it is done with animal attraction. The removal of grass before planting for HT is the same cost as the making of CR for farmers. The CR increases crop yield and consequently increases the benefit of crop cultivation.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion:

The study has shown that the use of tillage and soil amendments significantly improve some chemical properties of the soil as well as the growth and yield of millet and sorghum in the Sahelian zone of Mali. Contour ridge increased soil organic matter and the growth, biomass and grain yields of millet and sorghum more than the hoe tillage.

Soil pH was significantly increased under 5 Mg ha^{-1} Manure + 50 kg ha^{-1} Urea under millet cultivation. Nitrogen use efficiency was also better under contour ridge.

Among the soil amendments, the application of manure at 5 Mg ha^{-1} with 50 kg ha^{-1} of urea and 750 kg ha^{-1} lime gave the highest millet grain yield of 1321 kg ha^{-1}. The highest grain yield of sorghum was recorded under manure at 5 Mg ha^{-1}.

Biomass of 8508 kg ha^{-1} and 17995 kg ha^{-1} for millet and sorghum respectively were produced under 5 Mg ha^{-1} Manure + 50 kg ha^{-1} Urea + 750 kg ha^{-1} Lime, and 5 Mg ha^{-1} Manure + 50 kg ha^{-1} Urea + 100 kg ha^{-1} RP respectively.

The value cost ratio under all the treatments was < 2.0. However, in relative terms, the application of 5 Mg ha^{-1} Manure under contour ridge was the most profitable among the amendments with values of 1.8 and 1.0 under millet and sorghum respectively.

6.2 Recommendations

Studies are required to map out locally available organic materials which could be acquired at moderate cost to improve the profitability of manure and compost.

The profitability of contour ridge could be used as basis to train farmers in contour ridging for the production of millet and sorghum vis a vis their local hoe tillage.

Introduction of rock phosphate subsidized prices to rural farmers could help in replenishing nutrient (P) capital of cultivated fields.

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