GROWTH AND YIELD OF SORGHUM UNDER DIFFERENT CONSERVATION TILLAGE AND WATER AND NUTRIENT MANAGEMENT PRACTICES IN THE SOUTH SUDAN ZONE OF BURKINA FASO

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DECLARATION

I hereby declare that this submission is my own work toward the PhD 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 acknowledgment has been made in the text.

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ABSTRACT

A study was conducted in Nadion, located in the South Sudan zone of Burkina Faso to assess the impact of no-till, tied ridging; ripping and conventional tillage combined with soil fertility management options on soil chemical and physical properties and on sorghum growth and yield. The fertility management options were Control, 2.5 Mg ha^{-1} of compost, 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of Urea, mulching (100 % crop residues applied and 2.5 Mg ha^{-1} of compost + 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of Urea. The experiment was factorial, laid out in split-plot and arranged in a randomized complete block design with three replications on a Lixisol with a slope of 1.5%. Soil moisture was monitored weekly. Soil bulk density, total porosity, aeration porosity were assessed. Infiltration measurements were done after harvesting. Soil samples were analysed for pH, organic carbon, total nutrient (N, P, K) and available nitrogen (NO_3^- -N and NH_4^+). Plant and grain samples were analysed for nutrient uptake and utilization. Mixed model analysis of the results indicated that conventional tillage decreased soil bulk density at the ploughing depth and increased the total porosity and aeration porosity. Soil structural stability index (StI) tended to decrease under ripping, tied ridging and conventional tillage practices after two years. Infiltration rate varied between 0.82 and 1.15 cm h^{-1} in the order of Ripping > Conventional tillage > Tied ridging > Zero tillage. Field saturated hydraulic conductivity (Ks) varied from moderately rapid (6-8 cm h^{-1}) under ripping, through rapid (8 – 12 cm h^{-1}) under Conventional, to very rapid (>12 cm h^{-1}) under Zero and Tied ridging. All the tillage treatments recorded greater sorptivity than the Zero tillage with the percentage increment being 3, 7 and 10 under Tied ridging, Conventional and Ripping respectively. The pore sizes varied from 6 to 105 µm (0.006 to 0.105 mm) under Tied ridging and Ripping respectively with a trend of

Tied ridging > Zero tillage > Conventional tillage > Ripping. Infiltration rate the soil amendments was in the order of NPK + Urea > Control > Compost > Mulch > Compost + NPK + Urea. Saturated hydraulic conductivity was moderately rapid under control, rapid under compost and very rapid under mulch, NPK + Urea and compost + NPK +Urea. Sorptivity under the amendments was in a decreasing order of Compost > Control > NPK + Urea > Compost + NPK + Urea > Mulch with values ranging from 0.535 to 0.781 mm $S^{1/2}$ for mulch and compost respectively. The hydraulically functioning pores size recorded under the various soil amendments ranged from 0.008 mm to 0.082 mm in an increasing order of Control < Compost < NPK + Urea < Mulch < Compost + NPK + Urea. At the 0-30 cm depth, soil water stock was significantly higher under Zero tillage than the remaining tillage practices from the third to the ninth week. The mean weekly water stock over the 12 week period of measurement at 30-50 cm depth followed a trend of Tied ridging > Conventional tillage > Zero tillage > Ripping with a range between 31.78 and 43.72 mm for Ripping and Tied ridging respectively. The mean cumulative soil moisture stock at 0-50 cm also varied significantly only at the 4th and 5th weeks with the Tied ridging recording the highest. Sorghum straw mulch significantly improved soil water stock than the Control at all depths. NPK + Urea application decreased soil pH while the Compost and the Compost + NPK + Urea application led to an increase in the pH. During the peak rainfall period, ammonium - N content decreased under Tied-ridging and Conventional tillage practices while it increased under Ripping and Zero tillage practices. Tied-ridging and Conventional tillage improved sorghum plant P uptake. The application of NPK + urea and its combination with compost also increased nutrient uptake but reduced their utilization compared to the Control. The combined application of Compost and mineral fertilisers improved soil organic carbon, total nitrogen, total phosphorus and total potassium content. In 2012, Ripping increased sorghum grain yield by 14% while the Conventional tillage and the Tied-ridging decreased it by 29% and 40% compared to the Zero tillage practice. The application of Compost + NPK + urea, NPK + Urea and Compost led to 74%, 50% and 29% increase respectively in grain yield over the Control. The two - years cumulative effect of Tied-ridging x Compost + NPK + Urea increased sorghum grain yield by 13% and 28% compared respectively with Zero tillage and Conventional tillage with the same fertility management options.

DEDICATION

To

My dad Ganadolo, my mum Coulibaly Habi, my wife Toure Halimatou Aboubacar and my Children Amira and Charifa

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CHAPTER ONE

1.0. INTRODUCTION

1.1. Background

Sub-Saharan Africa is one region where per capita food production, mainly by rainfed agriculture, is either in decline or has stagnated at inadequate levels (FAO, 2007). Recent report indicates that while southern Africa has experienced a high variability in the decline of food production, western Africa has succeeded in increasing per capita food production significantly.(Pinstrup - Andersen *et al*., 2000).

Among the causal factors are the high variability in weather conditions, low inherent soil fertility, nutrient depletion without the requisite replenishment, breakdown of traditional practices and the low priority accorded agricultural development in the rural sector by governments (Sanchez *et al.*, 1997). Yield gap analyses in several studies, including those in the semi - arid regions, further indicate that water related constraints in rainfed agriculture in the water - scarce tropics are often due more to high rainfall characterized by high intensities, spatial and temporal variability and significant loss of water through runoff and evaporation from the soil than the annual cumulative amount (Sivakumar and Wallace, 1991; Rockström *et al*., 1998). In this context, Barron *et al*. (2003) indicated that in areas where water constitutes a major limiting factor to crop growth and yield, agricultural dry spells and drought cause more yield decline than meteorological drought.

Apart from the moisture stress constraints, large quantities of nutrients have been removed from farmers' field through crop uptake and erosion over the years without replenishment. This has resulted in soil nutrient depletion (Sédogo, 1981) with annual depletion rates per hectare of 22 kg nitrogen (N), 2.5 kg phosphorus (P) and

15 kg potassium (K) over a 30 year period from cultivated land in 37 African countries equivalent to an annual loss of US$ 4 billion in fertilizer (Sanchez *et al*., 1998). In Burkina Faso, estimates indicate that in 1983, nutrient mining from 6.6 million hectares of cultivated land amounted to a total loss of 95,000 Mg of N, 28,000 Mg of P_2O_5 and 79,000 Mg of K_2O, equivalent to US$ 159 million of NPK fertilizer (MAHRH, 1999).

In the midst of these constraints, enhancing productivity and livelihoods in the arid and semi - arid regions would require the adaptation and implementation of sustainable land and water management technologies which enhance soil infiltrability and water storage, soil fertility as well as water and nutrient use efficiency (Nicou *et al*., 1990; Zougmoré *et al*., 2000; Barron *et al*., 2003; Zougmoré *et al*., 2004). On the other hand, the creation of incentives for African farmers to invest in sustainable land and water management (SLWM) technologies for productivity increase requires improvement in agricultural production and product markets (Abdulai and Delgado, 1995; Sanchez *et al*., 1999). According to Shaxson *et al*. (1997), such increases in productivity must come largely through better use of land already in production since the potential to develop new lands is severely limited. It is in this context that several authors have advocated for the development of adapted technologies for resource management that optimize efficient use of soil and the limited water for the attainment of sustainable agricultural production and food security in Sahelian regions (Mando *et al*., 1999; Zougmoré *et al*., 2004).

Several land and water management technologies including conservation agriculture, which encompasses a wide range of integrated technologies such as reduced tillage, earth and stone bunds, dikes, half - moon and zai have been tested in the semi - arid and Savana region for their impact on soil infiltrability and moisture storage (Nicou *et al*, 1990; Zougmoré *et al*., 2000; Zougmoré *et al*., 2004). However, given the low inherent soil fertility status of the soils of the semi - arid and arid regions, available evidence have demonstrated the need to combine improved water infiltration and storage with soil fertility management to achieve the desired goal of enhanced water, soil and crop productivity (Sédogo, 1981; Sédogo, 1993; Lal *et al*., 1998; Zougmoré *et al*.; 2000; Zougmoré *et al*.; 2004, Odunze *et al*., 2012).

This need was the basis of the several studies on integrated nutrient management involving the combined use of mineral and organic fertilizers under soil and water conservation technologies in the Sudan - Sahel and Sahelian agroecological zones of Burkina Faso (Mando *et al*., 2001; Zougmoré *et al*., 2003). However, there is lack of such studies in the relatively less degraded south Sudan zone. Yet, indications are that, land degradation in this zone is on the increase as a result of demographic pressures, reduced land cover and poor land management practices.

Studies have demonstrated that 20 years ago, when rainfall amount and distribution were favourable for plant growth, tied ridging with other practices that impound water for enhanced in - situ moisture storage was not suitable in the south Sudan agro - ecological zone (Bado, 1990, personal communication) because it caused water logging and plant asphyxia. However, present day climate change has led to a significant reduction in rainfall amount, number of rainy days and erratic distribution (Roncoli *et al*., 2009). Soil and water conservation has therefore become very urgent now than ever before for suitable crop production in the south Sudan agro-ecological zone. This requires rekindling the hitherto stagnated research into soil water conservation techniques such as zero tillage, tied - ridging and zai which have been found to be effective in the drier northern Sudan zone. It is envisaged that such practices, among others, when adopted could reduce the adverse impacts of dry spells on crop yields and contribute to the restoration of degraded lands as well as halting the on - going land degradation in the south Sudan agro - ecological zone. It is in this context that this study was undertaken.

1.2. Research objective

The main objective of the study was to identify and assess adapted soil and water conservation and nutrient management technologies for sorghum production in the south-Sudan zone of Burkina Faso.

Specific objectives

The specific objectives were to assess the impact of different tillage practices and soil amendments on:

i. some soil physical parameters: dry bulk density, porosity, saturated hydraulic conductivity, aggregate stability and soil moisture storage;
ii. soil chemical parameters: pH, soil organic carbon, soil nutrients (N, P and K contents) and uptake and nitrogen dynamics;
iii. the growth and yield of sorghum.

The above specific objectives were formulated based on the following hypotheses:

i. suitable soil and water management technologies can be identified for sorghum-based cropping system in the south Sudan zone of Burkina Faso;
ii. tillage and soil amendments and their interactions affect the magnitude of soil physical and chemical properties;
iii. tillage and soil amendments and their interactions influence the growth and yield of sorghum.

CHAPTER TWO

2.0. LITERATURE REVIEW

In this chapter, a general overview of agriculture and food security in Sub-Saharan Africa has been reviewed. The position of Burkina Faso, where this study was undertaken, relative to the general state of agriculture and food security in Africa, has been examined to reveal gaps which require remedial measures. Previous works and efforts in providing solutions to soil and crop productivity constraints in Burkina Faso have been extensively reviewed to serve as a basis for the choice of potential adaptive soil management technologies for the current study. This review covers, among others, the use and impacts of different soil management practices, particularly tillage, mineral fertilizers and organic amendments such as compost and mulches, on soil and crop productivity. Particular attention has been directed at the impacts of these practices on in-situ water harvesting and use given the peculiar circumstances of unimodal rainfall regime, limited rainy days, long dry periods and soil moisture constraints to crop production in Burkina Faso.

2.1. State of agriculture and food security in sub - Saharan Africa and Burkina Faso

In the past decades, the main objective of agricultural research was to increase food production through the development of new technologies (Lompo, 2012). The Green Revolution has resulted in higher yields, especially in developed countries. However, it had negative impacts on the environment and has not been effective in all developing countries (IAASTD, 2008). Nowadays, environmental degradation has reached a critical level and is becoming a major concern for humanity (Kulkarni and Ramachandra, 2006). In addition to environmental degradation, the situation is worsened by an increasing demand for food from the already limited natural resources, and by persistent poverty, malnutrition, and poor food and diet quality (Kulkarni and Ramachandra, 2006; IAASTD, 2008). Thus, agriculture today faces the challenge of being able to meet human food needs over the long term while safeguarding the integrity of natural resources.

Sub - Saharan Africa has the lowest food production compared to other regions of the world (UNECA, 2009; Hazell *et al*., 2010) and there is a huge gap between food demand and food production. This situation is worsening because of the decreasing crop yield and the continuous population growth. To overcome this situation, food production has to be increased in a sustainable manner (Pretty, 1999; IFPRI, 1995). However, land degradation in Africa is an important concern since up to 65% of arable land is already degraded (Pretty, 1999). Past experiences which resulted in agricultural development in industrialized countries have not been particularly successful in Africa (Pretty, 1999; Hazell *et al*., 2010). Therefore, food production must be enhanced using sustainable soil and water management practices that have recently been identified (Pretty, 1999). In Africa, specifically Sub-Saharan Africa, smallholder farmers and pastoralists rely on subsistence agriculture for their livelihood (Hazell *et al*., 2010). Agriculture in Sub-Saharan Africa (SSA) is characterized by low input and low productivity, lack of infrastructure, insufficient agricultural research findings, low adoption of research results, insufficient linkages between agriculture and other sectors, unfavourable policy and regulatory environment, and adverse impacts of climate change (UNECA, 2009).

Demographic projections indicate that the world population will increase by 50% to reach 9 billion by 2050, whereas the population of sub-Saharan Africa (SSA) will increase by 150% (from 0.8 to 2 billion people) during the same period (FAO, 2011).

An estimated 70% increase (more than this in Africa) in agricultural production is required to meet the increased demand for food (FAO, 2011). However except for some few cases where an improvement in agricultural productivity was noted, food production in Africa has remained stagnant at around 1 ton of cereal / ha during the last 40 years (FAO, 2011). While the number of people suffering from hunger in the world decreased by 132 million during the past 20 years, 20 million increases has been observed in SSA. Africa is therefore a net importer of food with a trade deficit of 22 billion U.S. dollars in 2007 (FAO, 2011).

Burkina Faso is one of the African countries with a high rate of economic growth and GDP - real growth rate of 4.2% and is the 95th largest in the world (INSD, 2006). However, there is an on-going debate on whether this growth rate is sufficient to generate the necessary transformation of agriculture and reverse the downward trend in per capita agricultural production recorded during the last 40 years. This notwithstanding, there is the need to improve soil and crop productivity of the many smallholder farms continue to feed the country through the adoption of sustainable land management practices

2.2. Soil management practices

In this section, a general overview of tillage practices, the organic and mineral fertilizers effect on selected soil chemical and physical properties and growth and yield have been provided through the review of relevant literature.

2.2.1. Tillage

According to Blanco-Canqui and Lal (2008), tillage is a major component of management. It refers to the mechanical operations performed for seedbed preparation and optimum plant growth. A system of tillage involves a sequence of mechanical operations including tilling the soil, chopping and incorporating crop residues, planting crops, controlling weeds before and during plant growth, applying fertilizers and pesticides and harvesting crops.

The main objectives of tillage are weed control, modification of soil's physical properties within the rooting zone and the control of runoff and erosion (Ouattara, 2007).

The impacts of tillage on soils and environment are hard to generalize (Berhe *et al*., 2012). It is generally believed that when depth of ploughing is shallow (<10 cm soil depth), it results in very shallow loosened soil the furrow bottom and reduces infiltration. Deeper ploughing (>20 cm soil depth), on the other hand, increases infiltration rate especially immediately after tillage (Ouattara, 2007).

Tillage temporarily increases soil porosity, surface roughness and water infiltration, affects nutrient availability, improves root growth and crop yield (Nicou *et al.,* 1993; Ouattara, 2007). However, important and undesirable side effects of tillage are sub-soil compaction (Halde *et al*., 2011), decreased soil carbon especially under soil inversion and disturbance and increased erosion (Ouattara, 2007).

2.2.2. Types of tillage systems

Tillage systems are grouped into two main categories: conventional and conservation tillage.

2.2.2.1. Conventional tillage

Blanco-Canqui and Lal (2008) defined conventional tillage as any tillage systems that inverts soil and alters the natural soil structure. It primarily refers to mouldboard ploughing. Typically, it includes ploughing and harrowing to produce fine seedbed and removal of most of the plant residues from the previous crop (Ouattara, 1994).

Ploughing is done with a mouldboard or disc-plough which inverts the soil to a depth of 10 – 20 cm.

2.2.2.2. Conservation tillage

Conservation tillage is a collective umbrella term commonly used to refer to no-tillage, direct-drilling, minimum-tillage and/or ridge-tillage to denote that the specific practice has a conservation goal of some nature (López-Garrido *et al*., 2011). Usually, the retention of 30% surface cover of residues immediately after planting characterizes the lower limit of classification for conservation-tillage. Other conservation objectives for the practice include conservation of time, fuel, earthworms, soil water, soil structure and nutrients. Thus residue levels alone do not adequately describe all conservation tillage practices.

Its principles and goals are defined as follow:

(i) Minimizing soil disturbance by mechanical tillage and thus seeding or planting directly into untilled soil, eliminating tillage altogether once the soil has been brought to good condition, and keeping soil disturbance from cultural operations to the minimum possible;

(ii) Maintaining year-round organic matter cover over the soil, including specially introduced cover crops and intercrops and/or the mulch provided by retained residues from the previous crop;

(iii) Diversifying crop rotations, sequences and associations, adapted to local environmental conditions, and including appropriate nitrogen fixing legumes; such rotations and associations contribute to maintaining biodiversity above and in the soil, contribute nitrogen to the soil/plant system, and help avoid build-up of pest populations.

Conservation tillage uses some of the principles of conservation agriculture (CA), but has more soil disturbance. According to FAO (2001), Conservation agriculture maintains a permanent or semi-permanent organic soil cover. This can be a growing crop or dead mulch. Its function is to protect the soil physically from the sun, rain and wind and to feed soil biota. The soil micro-organisms and soil fauna take over the tillage function and soil nutrient balancing. Mechanical tillage disturbs this process. Therefore, zero or minimum tillage and direct seeding are important elements of CA. A varied crop rotation is also important to avoid disease and pest problems (FAO, 2001).

2.2.2.2.1. No tillage

No tillage refers to the system whereby tillage is restricted to that necessary for planting the seed. Sowing takes place directly into stubble of the previous crop and weeds are controlled by herbicides. The practice has been found to increase the percentage of water-stable aggregates in the soil compared to ploughing (Ouattara, 1994; Ouattara, 2007). No tillage reduced erosion rate under maize (Outtara, 2007) and sorghum (Zida, 2011) in Burkina Faso to levels comparable to those achieved by cereal and cowpea intercropping system. In addition, no tillage was not always effective in the first year of its implementation because of the low percentage crop residues on the surface (Ouattara, 1994)

2.2.2.2.2. Mulch tillage

Mulch tillage refers to the use of large amounts of residues to control weeds. In many cases, lower yields have prevented the widespread take-up of stubble-mulch tillage (Mando *et al.* 1997). When tested on Lixisols and Luvisols, in Burkina Faso under continuous sorghum production Zougmore *et al.*, (2003) observed mulch tillage practice to reduce water erosion compared to conventional tillage. Mulch tillage did not lead to an increase in the aggregate stability of the soil compared with conventional tillage (Ouattara, 1994). However mulch tillage has been successful in wind erosion control and soil moisture storage (Zougmore, 2003).

2.2.2.2.3. Minimum tillage

Minimum tillage or reduced tillage or ripping refers to practices using chiseling to prepare the seed bed whilst retaining a 15 – 25 per cent residue cover (FAO, 2001). The minimum tilled plot retained moisture and then reduced the cracking which plays a key role in improving infiltration of water in these soils (Ouattara, 2007). After some 20 years of reduced tillage in Pennsylvania, soil organic carbon was 5 Mg ha^{-1} higher than on similar conventional tillage soils but the technique was found to create problems for farmers, with the accumulation of crop residues on the soil surface (Duiker, 2011).

2.2.2.2.4. Tied ridging

Tied-ridging in which ridges are connected with cross-ties over the intervening furrows, is an improvement over the traditional ridge-furrow system. The system results in a series of rectangular depressions which impound water during rain. Under the tied ridging practice the soil is left undisturbed from harvest to planting except for strips up to one-third of the row width. Planting is completed on the ridge and usually involves the removal of the top of the ridge (FAO, 2001). Residue is left on the surface between the ridges. Ridges are rebuilt during cultivation. The ridger has two adjustable discs angled to form a wide `V' shape. Although the unit looks heavy, the draft requirement is actually less than that required for the conventional mouldboard ploughs. Depending on the ridge requirements, the disc sizes and shapes can be varied. Ridges made using this technology can be tied using hand hoes at variable spacing. The ridging has been found to increase the yields of millet, maize and cotton years of average and below average rainfall in Burkina Faso compared with open ridging or flat planting due to better water retention (Ouattara, 1994; Zida, 2011). Lower yields were however obtained for crops which are sensitive to water logging (e.g. cowpea) (Hulugalle, 1988). In Zimbabwe, Vogel (1994) reported tied ridging with no till to produce soil loss less than 0.5 Mg ha^{-1} over three-year period compared with up to 9.5 Mg ha^{-1} for conventional ploughing with mouldboard under maize cultivation on erodible sandy soils.

2.2.2.3. Effect of tillage on soil structural stability

Structure stability is defined as the resistance of the soil structure to external factors such as water and equipment (Gray, 1996). Soils that naturally have a good structure in the long term have a 'stable' soil structure; those that would naturally lose all aggregation have an 'unstable' structure (Ouattara, 2007). Soil structural stability is a unique property of the soil that has a profound effect on the behaviour of soils, such as water holding capacity, nutrient retention and supply, drainage, and nutrient leaching. Soil structural degradation may be due mostly by raindrop impact, tillage operation and continuous cropping without organic inputs (Duiker, 2011).

The reduced aggregation in conventional tillage is due to the effects of tillage on aggregation (Ouattara, 1994; Six and Paustin, 2014). According to Six and Paustin (2014), even when conventional tillage results in a good structural distribution, the structural components are weaker to resist water slaking than in zero tillage situations with crop residue retention, where the soil becomes more stable and less susceptible to structural deterioration.

Mechanical disturbance of soil structure through tillage results in a direct breakdown of soil aggregates and an increased turnover of aggregates (Six and Paustin, 2014) and fragments of roots and mycorrhizal hyphae, which are very important for macroaggregates binding (Bronick and Lal, 2005). Most of the time, soil organic matter redistribution takes place after tilling. There is a strong correlation between soil organic carbon and aggregate stability (Ouattara, 1994). Even small changes in soil organic carbon can affect the stability of macro-aggregates (Verhulst *et al*., 2010).

Soil organic matter can increase both soil resistance and resilience to deformation and improve soil macro-porosity (Kay *et al*., 2002). Higher organic matter content in the topsoil reduces slaking and disintegration of aggregates when they are wetted (Verhulst *et al*., 2010). Crops can affect soil aggregation by their rooting system because plant roots are important binding agents at the scale of macroaggregates (Bandyopadhyay *et al.*, 2014).

Soil degradation, defined as the loss in soil productivity, is closely related to the alteration of certain soil physical, chemical, and biological properties (Albadalejo *et al*., 1998). Organic matter is one of the most important and well known aggregates stabilizing agents in soils. Ouattara (1994) and Zida (2011) showed that it takes time for tillage to significantly affect soil organic carbon, clay and silt content. The relationship between soil organic matter content and soil structural stability have been well documented (Le Bissonnais, 1996 and Ouattara, 1994). Zida (2011) observed a reduction in soil Structural degradation index (StI) value due to a decrease in soil total clay and silt content by both wind and water erosion after tilling.

2.2.2.4. Effect of tillage practices on soil bulk density and porosity

Bulk density is a soil quality indicator which can be used to evaluate soil structure under various tillage practices (Hou *et al.*, 2012). It affects infiltration, rooting depth, available water capacity, soil porosity, plant nutrient availability, and activity of soil microorganisms, which influence key soil processes and productivity. For soils with similar texture, it is only the changes in soil structure that govern soil porosity and water dynamics. Several authors have reported significant impacts of tillage on bulk density and porosity (Meek *et al*., 1992 and Ouattara, 1994). In most races, higher bulk densities have been recorded under zero tillage than conventional tillage. Zida (2011) found soil bulk density to increase under zero tillage and ripping while it decreased under conventional tillage systems. They ascribed the differences to be due to the change in soil structure after tilling. Higher bulk density under no-tillage vis a vis conventional tillage have been reported by Ouattara (1994) and Xu and Mermoud (2001). Similarly, Dam *et al*. (2005) reported a 10% higher in no tillage (1.37 Mg m^{-3}) than in conventional tillage (1.23 Mg m^{-3}). At saria, a bulk density range 1.4 to 1.5 Mg m^{-3} was reported under inversion tillage and 1.6 to 1.7 Mg m^{-3} under no-tillage on a Lixisol (Zida, 2011). In addition, Diaz-Zorita *et al*. (2004) found higher bulk density in the soil surface layer of direct sowings than in soils of other tillage systems. On the other hand, Roscoe and Buurman (2003) found greater bulk density values under conventional tillage systems when compared to no-tillage. The greater bulk density was due to the compaction by tractor and the rain drops. Increase in soil bulk density was observed under tied ridging compared to no tillage practice (Chaplain *et al.*, 2011) while no differences were observed between ripping and zero tillage practice (Zida, 2011). The magnitude of bulk density varies with depth and the time of measurement after tillage imposition (Dam *et al.*, 2005; Lal *et* *al*., 1994). Naturally bulk density increases with due to the care burden the topsoil on the subsoil. Immediately after conventional tillage, bulk density is lowest compared to other tillage as observed by Evans *et al.* (1996). With continuous tillage, bulk density is greater at depth of conventional tillage than others (Lal *et al.,* 1994). According to Ouattara (1994), the factors which account of increased bulk density decrease porosity and vice versa.

2.2.2.5. Effect of tillage on soil hydraulic characteristics

Hydraulic conductivity in agricultural soils is affected by the porosity and pore-size distribution, bulk density, soil compaction and aggregation (Kutilex, 2004; Lipiec *et al*., 2006). According to Truman *et al*. (2011), there are many factors which influence soil water infiltration. These include soil structure, aggregation, soil bulk density, soil moisture, organic matter content, macro-pores quantity and continuity, soil texture, dye application methods, etc. and most of them are greatly sensitive to tillage practices. Soil water infiltration is reported to be directly affected by soil tillage management (Moret and Arrúe, 2007).

Effective porosity of a soil is dependent on macro-pores, and has been related to saturated hydraulic conductivity (Ahuja *et al*., 1989; Zhang *et al*., 2006). An increase in soil hydraulic conductivity under conventional tillage has been observed by Nicou and Charreau (1985) and Zougmoré *et al*. (2004) and was attributed to the improvement of soil porosity. Logsdon *et al*. (1999) and Bhattacharyya *et al*. (2006) observed low hydraulic conductivity of soils under zero tillage and ripping systems due to the soil compaction leading to low porosity under these practices. On the other hand, Capowiez *et al*. (2009) reported under reduced tillage an improvement of infiltration more than that in conventional tillage and ripping due to large macro-pores under reduced tillage. Several authors showed an improvement in soil hydraulic characteristics under zero tillage or minimum tillage practices compared to other tillage options due to the maintenance of soil structure and the hydraulically functioning pores size under these tillage practices (Govaerts *et al*., 2007; Ouattara *et al*., 2007 and Presley *et al*., 2012).

Soil moisture is the source of water for plant use particularly under rainfed agriculture (Zougmore, 2003). Soil moisture is highly important in ensuring good and uniform seed germination and seedling emergence (Arsyid *et al*., 2009), crop growth and yield. Soil moisture content is affected by tillage practices as observed by Zougmoré *et al.* (2004). Tillage operation move moist soil to the surface, increasing evaporation (Ouattara, 2007). By increasing infiltration and reducing runoff and evaporation compared to conventional tillage, zero tillage can improve soil water content and help buffer mid-season drought occurrences (Verhulst *et al*., 2011).

Ripping and tied ridging practices promote infiltration because of the bunds they create (Zougmore *et al*., 2004). Zougmoré *et al*. (2003) observed an increase in soil water content under tied ridging practice up to 20 % compared to the conventional tillage practice because of the high total porosity due to lower bulk density induced by soil structure disturbance due to tillage.

Studies have demonstrated that 20 years ago, when rainfall amount and distribution were favourable for plant growth, tied ridging with other practices that impound water for enhanced in-situ moisture storage was not suitable in the South Sudan agro-ecological zone (Bado, 1990, personal communication) because it caused water logging and plant asphyxia. However, present day climate change has led to a significant reduction in rainfall amount, number of rainy days and erratic distribution

(Roncoli *et al.*, 2009). Soil and water conservation has therefore become very urgent now than ever before for suitable crop production in the south Sudan agro-ecological zone.

2.2.2.6. Effect of tillage (soil moisture content) on available nitrogen mineralization

Nitrogen cycling in soils is thought to be highly related to variation in moisture. Soil moisture in turn varies with soil properties such as texture, organic matter content and tillage practice imposed which affect water-holding of the soils (Sleutel *et al.*, 2008), and the balance between inputs and outputs in the water budget in the soil profile. Variation in both intra and inter-seasonal rainfall can both change soil water content. While nitrogen cycling have widely been studies (Butturini *et al.*, 2003; Sleutel *et al.*, 2008). The effects of constant versus fluctuating soil moisture conditions on nitrogen mineralization have not been well documented. Huttunen *et al.* (2003) found that the effect of soil moisture content on nitrate production was related to the type of soil and the tillage practice imposed; suggesting that soil characteristics and water conservation measures constrain the response of soils to drying. In mineral soil, N mineralization is maximal at intermediate levels of soil moisture content (50-70% water-filled pore space) (Sleutel *et al.*, 2008). The range of moisture producing maximal rates varied with soil texture and organic matter content. Fluctuating moisture conditions could result in either enhanced N mineralization (Mikha *et al.*, 2005) or alternatively could result in decreased net release of mineral N, as N that is mineralized and nitrified during dry periods is denitrified during wet period.

The nitrification is the microbial oxidation of ammonia to nitrite and further to nitrate.

The nitrification process is in two steps:

1. Ammonia → Nitrite = $NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$
2. Nitrite → Nitrate = $NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$

These are a key set of reactions in relation to N losses since they transform the relatively immobile ammonium ion into nitrate, which can be leached or denitrified. The transformation of nitrite to nitrate occurs in the presence of water. Higher N losses through leaching and denitrification have been observed under tied ridging and conventional tillage by Constantin *et al*. (2011), Jin *et al*. (2013) and Castellano *et al*. (2014).

2.2.2.7. Effect of tillage and its interaction with amendment on nutrient uptake

Soil tillage influences both nutrient and soil moisture dynamics in the soil– plant system, which in turn affect nutrient use efficiency in a cropping system. Some of the tillage functions are to incorporate fertilizer and crop residues in the soil, improves soil aeration, and subsequently promote organic N and P mineralization (Dinnes *et al*., 2002; Yoong *et al*., 2001). The tillage system can influence soil N availability due to its impact on soil organic C and N mineralization and subsequent plant N use or accumulation (Sanju and Singh, 2001). Compared with NT, the conventional tillage (CT) system can significantly change the mineralizable C and N pools (Woods and Schuman, 1988). However, a long-term NT system has potentially greater mineralizable C and N pools compared with CT (Doran, 1980). The plant N uptake can be altered by the different management practices and interactions between tillage system, N rate, and N application timing. The interactive effects of different tillage systems, such as, no-till, conventional tillage, or minimum tillage and N rate on grain N uptake was significant in increasing N removal with increasing N rate (Halvorson *et al*., 2001). An understanding of tillage and N source effect on the dynamics of N availability in soil and plant N uptake through the growing season at different growth stages is essential for determining the efficiency of N management. As the N availability is affected by the tillage system, P availability can equally be affected, leading to a P deficiency in many cropping systems. Many soils have large reserves of total P, but low levels of available P (Ortiz-Monasterio *et al*., 2002). However, plant P uptake varies with soil P and moisture availability, and the concentration of P in plant tissue decreases with plant age and water stress (Payne *et al*., 1995). P uptake by sorghum increases under tillage practices that impove soil moisture storage (Fatondji, 2002). Compost can be a valuable source for plant P nutrient need. In a study comparing compost with chemical N and P fertilizer sources, it was found that corn yield and N and P uptake was similar for both N sources (Fatondji, 2002).

2.2.2.8. Effect of tillage practices on sorghum growth and yield

The growth and yield of sorghum have been found to be affected by tillage practice (Ouattara, 1994 ; Zougmore *et al*., 2003 ; Ouedraogo, 2007; Zida, 2011). Subsoil compaction reduces crop root growth, the availability and uptake of nutrients and water by plants resulting in a reduction in crop grain yields (Peng *et al*., 2011). Crop under no tillage practice are usually stunted and show water stress and nutrient deficiency symptoms compared to those under conventional tillage whose growth and yield are favourable due to increase porosity, water infiltration storage and better root development. Pieri (1992) in Burkina Faso, Kouyaté *et al.* (2000) in Mali and

Mesfin *et al.* (2010) in Ethiopia observed higher sorghum growth rate under tied ridging and conventional tillage practices than zero tillage and ripping.

Zero tillage and reduced tillage systems have been reported to perform better (Mrabet, 2002), similar and sometimes poorer than conventional tillage systems in terms of yield (Ouattara, 2007). Decrease in grain yield under tied ridging have also been reported in Kenya by Kihara *et al.* (2012) and was attributed to high rainfall. Studies showed that the positive effect of zero tillage on crop yield is observed after some years (Duiker, 2011 and Ogle *et al.*, 2012). Contrasting results were obtained by Zougmoré *et al.* (2004) in the Sahelian part of Burkina Faso where the annual rainfall is lower than 800 mm. They observed a decline in sorghum grain yield under zero tillage practice. These lower yields under zero tillage were attibuted to the water constraint. Tesfahunegn (2012) reported 45% increase in sorghum grain yield under tied ridging practice compared with zero tillage in Abergelle area in Northern Ethiopia.

In spite of this, farmers in semi-arid areas are not practising adapted tillage practices that improve soil water and the availability of N, P and K nutrients added as fertilizer to soils (Zougmoré *et al*., 2004).

2.2.3. Soil fertility management practices

In this section, a general overview of the effect of mineral fertilizer and organic amendment on soil physical and chemical properties, nutrient uptake, and sorghum growth and yield have been reviewed.

2.2.3.1. Effect of organic fertilizer on soil chemical properties

Organic materials play important role in soil fertility management (Ouattara, 2007). Islam *et al.* (2011) reported that organic materials serve as source of nutrients, influence nutrient availability and affect the release pattern of plant available nutrients. The addition of fallow vegetation or crop residues is important to the sustainability of the traditional agricultural systems since it increases water infiltration and retention, counteracts adverse phenomena like structure degradation and a decreasing cation-exchange capacity (CEC) (Sedogo, 1981). Kincaid (2002) reported that the CEC of the soils is largely dependent on the soil organic matter content. Organic matter can be added to soil by applying green manure, compost or animal manure etc. (McDonagh *et al.*, 2001). The advantages and drawbacks of specific organic inputs depend on the quality of the organic material (available nutrient contents, rate of decomposition, etc.), the soils' organic matter pool to which they contribute, and on the site characteristics (Bationo and Mokwunye, 1991; Magid and Kjærgaard, 2001; McNair Bostick *et al*., 2007). The effect of organic inputs on soil organic matter dynamics can be transient, temporary or relatively long-term (Vanlauwe *et al*., 2002).

Composting generally results in organic materials of high stability with low C/N ratio (McDonagh *et al.,* 2001). The types of compost vary according to the nature of material used (e.g. fresh plant and animal materials, crop residues, municipal waste and industrial waste) and its degree of decomposition (Mishra, *et al*., 2001). Cereal crop residue composts may release nutrients slowly into the soil, and thus over longer periods than crop residues (Mando *et al*., 2001; Sanchez *et al*., 2004, Ouédraogo, 2004). Compost can act as a soil ameliorant that is capable of changing the pH, moisture content, structure and nutrient contents of the soil (Semple, *et al*., 2001). As a carbon source it helps to improve the CEC, and both the physical and biological properties of the soil. Compost applications to soil retards crust formation, reduces runoff and effectively combats degradation of the structure of highly unstable soils (Albiach *et al*., 2001; Bresson *et al*., 2001). Compost also increases soil microbial biomass, earthworm (*Megadrili spp*) populations and biomass (Carpenter-Bogs *et al*., 2000). In addition, it has enormous potential for bioremediation because it can sustain diverse populations of micro-organisms (bacteria and fungi) with the potential to degrade a variety of pollutants (Kapanen and Itavaara, 2001). Compost generated from crop residues mixed with animal dung is often used for organic fertilization in West Africa (Ouédraogo *et al*., 2001; Bissala and Payne, 2006). A further advantage of compost is that farmers are generally aware of its capacity to sustain yields and improve soil quality.

In tropical soils, the impact of organic amendment on long-term carbon storage might be rather small (Mandal *et al*. 2007). However, many studies noted their beneficial effects on nutrient cycling (Ngo *et al*., 2012; Kaur *et al*., 2005). Long-term experiments have been carried out to study the effects of organic matter from diverse sources on the properties of agricultural land, and to identify appropriate soil fertility management (Sedogo, 1981; Sédogo, 1993; Ouattara, 1994; Mando *et al.*, 2005; Zida, 2011).

The soil pH is a very good indication of soil fertility. Haynes and Mokolobate (2001) reported that the process of ammonification increases soil pH as OH^- is produced by NH_4^+ that is mineralized from organic matter. Ikerra *et al.* (2006) reported an increase in soil pH consecutive to compost application. Compost can act as a soil ameliorant that is capable of changing the pH of the soil (Ouattara, 1994). Bekunda *et al*. (1997) reported from selected experimental results in Africa that continuous application of mineral fertilizer (especially N fertilizer) without organic input led to soil acidification and decline in soil organic matter.

2.2.3.2. Effect of mulching on soil water content

Mulching is one of the management practices for increasing water use efficiency (WUE). Different types of materials such as wheat straw, rice straw, plastic film, grass, wood, sand, etc. are used as mulch. Mulching is one of the important agronomic practices in conserving the soil and modifying the soil physical environment (Ouattara, 2007). Mulch has the potential to control weed growth (Erenstein, 2002) and retain soil moisture (Manakul, 1994). Appropriate tillage and mulch practices are used to conserve soil moisture and increase the yield of crops.

Liu *et al*. (2012) stated that mulching improves the ecological environment of the soil and increases soil water content. Rathore *et al.* (1998) reported that more water is conserved in the soil profile during the early growth period with mulch than without it. Favourable effects of residue mulching on soil water retention have been reported for the surface layer (Duiker and Lal, 1999). Conservation of soil moisture is one of the major advantages of mulch farming system. Mulching protects the soil from water loss. Crop residues at the soil surface shade the soil and serve as a vapour barrier against moisture losses from the soil and thus increasing soil water content (Mulumba and Lal, 2008).

Hatfield *et al*. (2001) reported 34-50% reduction in soil water evaporation as a result of crop residue mulching. Ouattara *et al* (2006) observed higher soil water content under mulching practice compared to the control.

The practice of mulching increased soil organic carbon content after several years of application (Paustin *et al*., 1997). It also helps to improve soil fertility when the carbon / nitrogen ratio of the mulch is low, and immobilizes nitrogen when the carbon / nitrogen ratio is high (Zombré, 2003).

One of the major constraints to the use of mulching in semi-arid regions is the strong competition for the use of plant residues. They are not only used for making roofs or crafts and for feeding cattle (essential component of the economy of semi-arid areas), but are also used as a source of domestic energy. In this context, the allocation of residues for soil protection is often difficult (Mando *et al*., 1999). In sub-humid regions bushfires led to the disappearance of straw and constituted major factor limiting the use of mulch. Proper management of bush fires and a good integration of livestock farming are therefore required to maintain the mulching technique in the semi-arid zone.

2.2.3.3. Effect of organic amendment on soil aggregate stability

Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles. The spaces between the aggregates provide pore space for retention and exchange of air and water (USDA, 1996). Aggregate stability refers to the ability of soil aggregates to resist disruption when outside forces (usually associated with water) are applied. Aggregation affects erosion, movement of water, and plant root growth. Desirable aggregates resist dispersion by rainfall and movement by water (Ouattara *et al*., 2006).

Aggregates are known to physically protect C and N (Ouattara, 1994). Aggregates physically protect soil organic matter (SOM) by (1) forming a physical barrier between microorganisms plus microbial enzymes and their substrates, (2) controlling food web interactions, and (3) influencing microbial turnover (Ouattara *et al*., 2008). A closer look at the processes involved in aggregate formation and stabilization in temperate versus tropical soils illustrates the close relationship between soil biota and SOM dynamics (Ouattara *et al*., 2008). In both temperate and tropical soils, several biological processes are responsible for the formation of initial unstable "biological" macro-aggregates.

The stability of aggregates is affected by soil texture, the predominant type of clay, extractable iron and extractable cations, the amount and type of organic matter present, and the type and size of the microbial population (Ouattara, 1994). Expansion and contraction of clay particles can shift and crack the soil mass and create or break apart aggregates (Ouattara, 1994). Calcium ions associated with clay generally promote aggregation, whereas sodium ions promote dispersion. Soils with over about 5 % iron oxides, expressed as elemental iron, tend to have greater aggregate stability (Ouattara *et al.*, 2008). Soils that have a high content of organic matter have greater aggregate stability. Additions of organic matter increases aggregate stability, primarily after decomposition begins and microorganisms have produced chemical breakdown products or mycelia have formed. Thus there is a great correlation between aggregates stability and soil organic matter content (Ouattara, 2007). It has also been shown, in both temperate and tropical soil, that aggregation decreases C and N mineralization (Six *et al.*, 2002).

2.2.3.4. Fertility management effect on nutrient (NPK) uptake

Soil nutrient uptake is highly influenced by the availability of nutrient in the soil. Several studies have shown an increase in sorghum nutrient uptake with an increase the soil available nutrient content (Fatondji, 2002; Sharif *et al.*, 2014).

Taalab *et al*. (2008) found that nitrogen uptake by sorghum under compost + NPK treatment was higher with 60 kg N ha^{-1} than no nitrogen. Sharif *et al*. (2014) and Ballaki and Badanur (2012) also observed higher N uptake by sorghum with incorporation of compost over fertilizer application. Findings have demonstrated a positive interaction between soil moisture and P uptake because improved soil moisture status increases soil P availability (Ballaki and Vandanur, 2012).

Sharif *et al.* (2014) indicated that total P uptake by sorghum may significantly increase with organic and mineral inputs over control. Erdal *et al*. (2000) reported that nutrients accumulations in plant were enhanced by the use of organic materials mixed with chemical fertilizers.

2.2.3.5. Fertility management option effect on sorghum growth and yield

Sorghum productivity is constrained by soil N and P availability (Sedogo, 1981). Traditionally, sorghum has been known for being nutrient-use efficient and managed with low fertilizer rates, but yields can be increased with higher fertilizer application rates (Maranville *et al*., 1980). Many studies have been published on N, P, or K fertilizer response in sorghum and their combination with compost (Kayuki *et al.* 2007; Wortmann *et al.*, 2007). Wortmann *et al.* (2007) have observed an increase in sorghum biomass and grain production by added N and P fertilizers only. They attributed the low yield response to K application to the fact that soils in the region had good capacity to supply sufficient K. Also dust deposition through the Harmattan winds, occurring annually in West Africa, may play a role in replenishing K. Studies have shown that such deposition supplies about 18.7 kg K ha^{-1} annually (Harris, 1998). As productivity of most soils in their native state is very low (Bationo *et al*., 1998), applying plant nutrients (compost, urea and NPK) to those poor soils can induce great positive reaction to crop production, particularly during good rainfall years when soil moisture constraint is less. In plots under compost application, the mineralization of compost releases not only macro-nutrients such as nitrogen and phosphorus but also considerable amounts of micronutrients for plant

(Zougmore *et al*., 2008). This is well demonstrated by Vanlauwe *et al.* (2011) who revealed greater agronomic performance when fertilizer was combined with manure or compost. Zida (2011) observed an improvement in sorghum growth and yield with the combination of compost and mineral fertilizer because of the amount of nutrients made available to the soil- crop system during the growing stage. The beneficial effects of combined compost and mineral fertilizers on sorghum growth have previously been highlighted by Ouedraogo (2004), Odlare *et al.* (2013) and Patel *et al*. (2013). Zougmore *et al.* (2003) attributed higher yields under compost + fertilizer treatments to the beneficial effect of nutrients being readily available from the fertilizers and also the effect of the mineral ferftilizer on the compost decomposition rate. Nutrients from compost and straw must first go through the decomposition process before they are made available for crop uptake. In compost treatments, nutrients availability depends on nutrient concentration and release in synchrony with crop needs (Bationo *et al*., 2012).

CHAPTER THREE

3.0. MATERIALS AND METHODS

This chapter describes the study area and the materials and methods used for the study.

3.1. The experimental site

3.1.1. Location

The experiment was conducted in Nadion (Figure 3.1), a village in the province of Sissili, which is about 175 km south of Ouagadougou (11°7'60" North and 2°13'0" East).

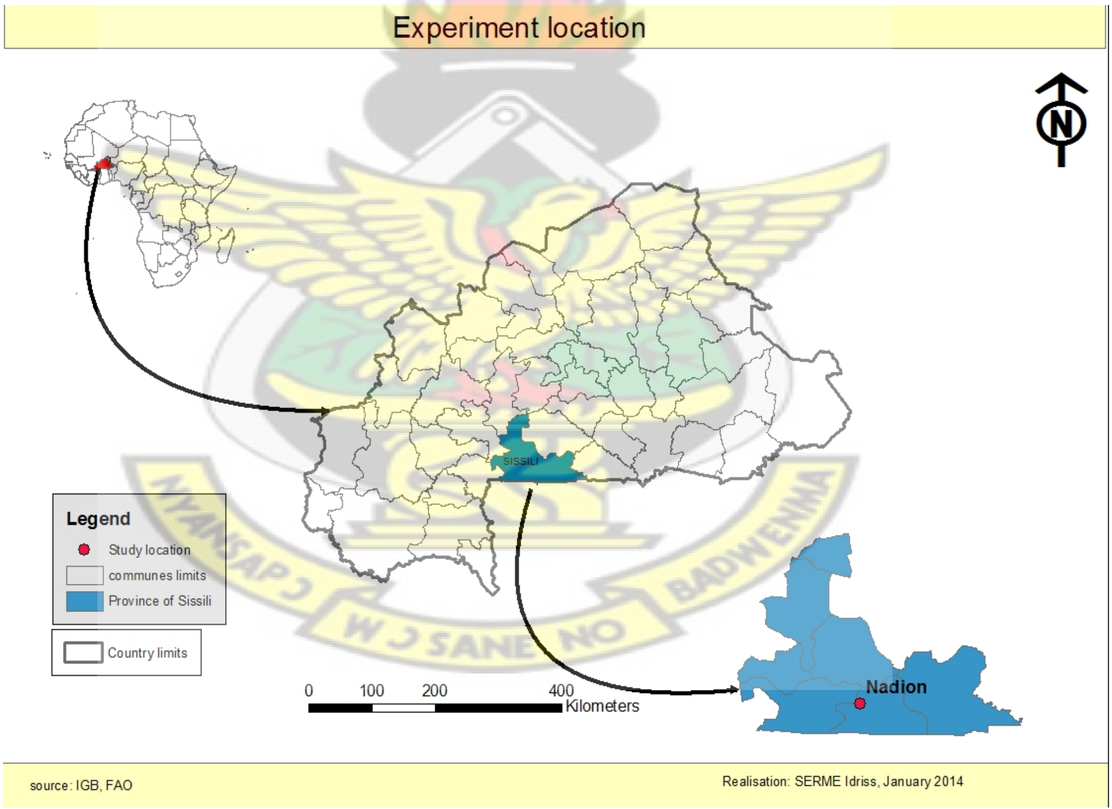

Figure 3.1: Map of the experimental site location.

3.1.2. Climate

Nadion is in the south Sudan agro - ecological zone of Burkina Faso (Fontes and Guinko, 1995). Rainfall is unimodal (Figures 3.2 and 3.3). The wet season starts from April and ends in October with annual rainfall amount varying between 1000 and 1200 mm. Rainfall is erratic in onset and distribution. The number of rainy days range between 54 and 69 days. Cumulative monthly rainfall amount showed a decrease in annual rainfall from 1989 to 2013 (Figure 3.4). This situation is not favourable for agricultural production and hence the need for green water conservation and a considerable reduction in blue water loss from the soil system.

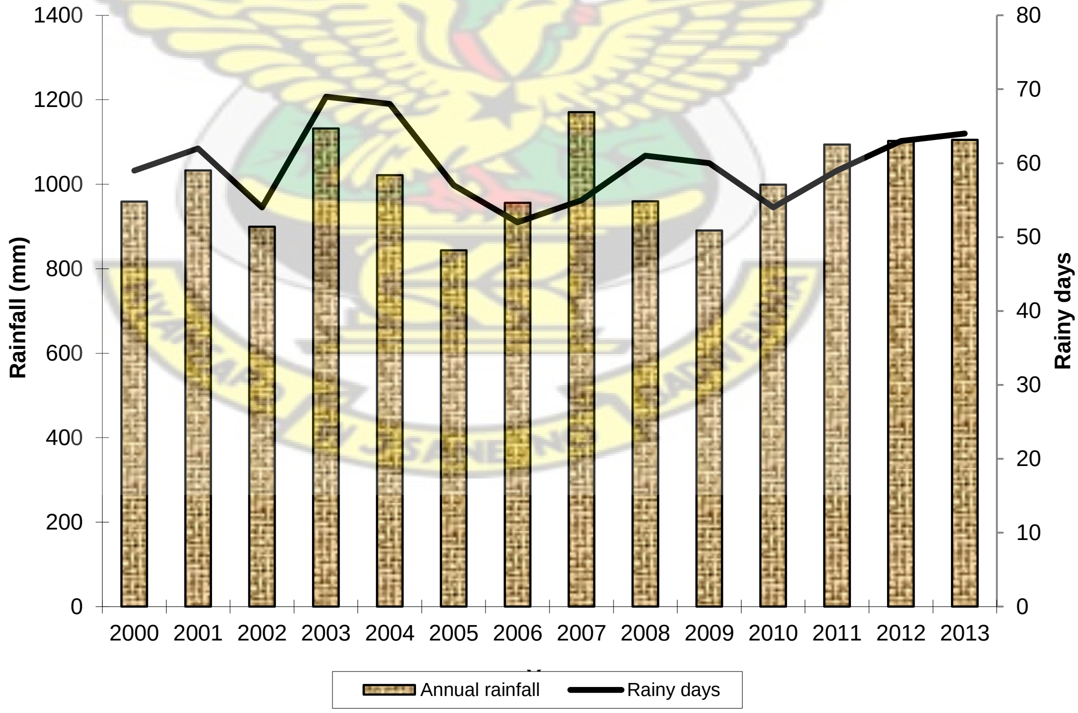

Figure 3.2 : Annual rainfall in Nadion from 2000 to 2013

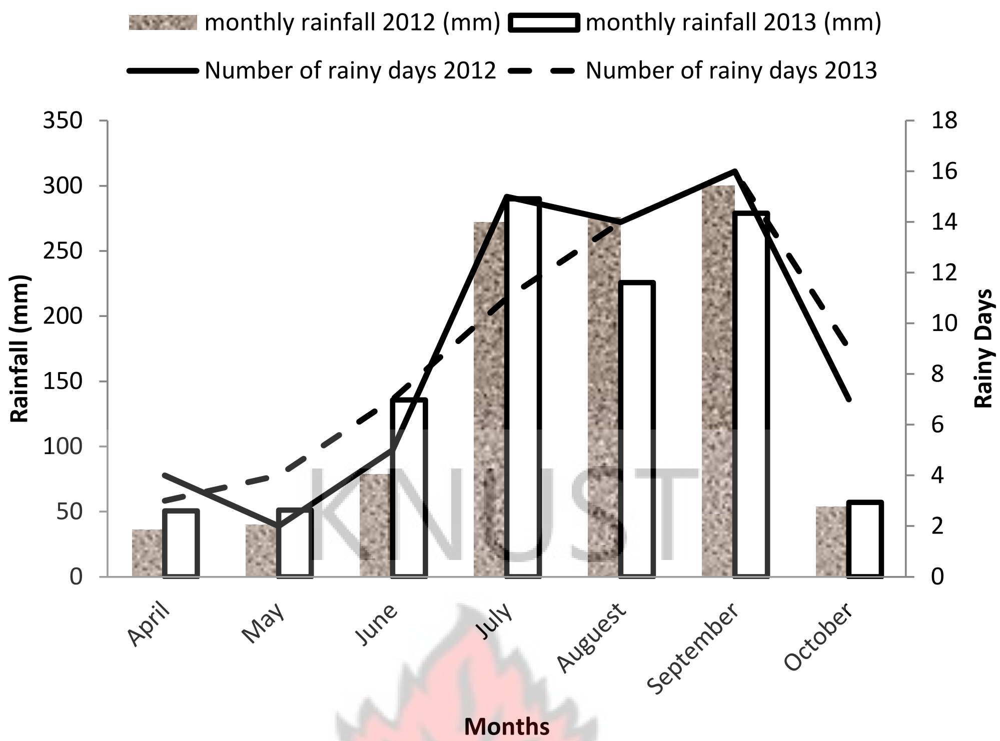

Figure 3.3 : Monthly rainfall in Nadion in 2012 and 2013

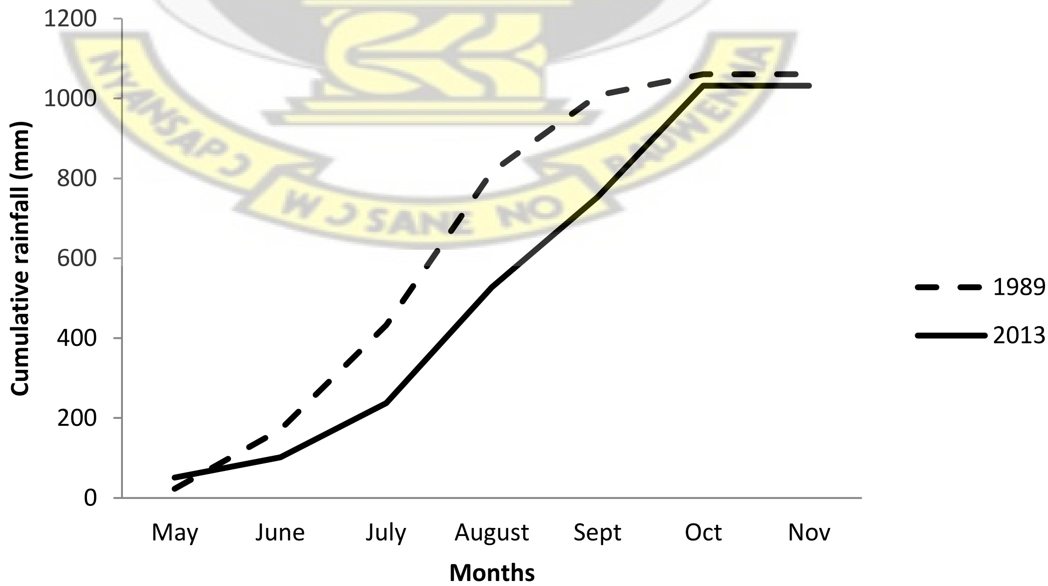

Figure 3.4: Rainfall distribution in Nadion in 1989 and 2013

3.1.3. The soil

The soil type is Lixisol (BUNASOL, 1990). It has a sandy loam texture with an average slope of 1%. The pH was 6 and fertility was low (Table 4.1). The soil is very shallow (less than 60 cm depth).

3.2. The experimental treatments and layout

The experiment was factorial, laid out in split - plot and arranged in a randomized complete block design with three replications.

The main plots comprised the following four tillage practices:

- No - till (direct planting);
- Minimum till (ripping);
- Tied ridging; the ridges were tied one month after sowing
- Conventional tillage (ploughing using animal to 15 cm depth).

The sub plots were:

- Control – Zero fertilizer, zero compost and zero crop residues
- 2.5 Mg of compost per ha every year
- 100 kg of NPK ha^{-1} (14-23-14) + 50 kg of urea ha^{-1} (46%N)
- 100% crop residues retained (for the first year 2 Mg ha^{-1} of crop residues were applied)
- 2.5 Mg of compost per ha + 100 kg of NPK ha^{-1} (14-23-14) and 50 kg of urea ha^{-1} (46 %N)

The main plots measured 10 m x 24 m while the sub plots were 10 m x 4m.

The total land area used for the study was 3072 m^2.

3.3. Compost preparation

The compost was prepared by the pit method. Sorghum straw, cattle manure and triple – super - phosphate (TSP) were used for the compost preparation. Two pits 1m deep, 2.5 m long and 1.5 m wide were used to prepare the compost. The proportion of straw to cattle manure was 4: 1 plus 50 kg of TSP per pit. Each pit comprised 6 layers of the composting materials with each layer being watered before the next. The pits were covered with a plastic sheet and watered twice a week with 200 litres of water over the 3 months composting period. The compost was turned 2 weeks and one month after installation and 2 weeks before the end of the composting period.

3.4. Land preparation and sowing

The field was cleared manually with cutlass before implementing the different tillage operations. Apart from the no - till, animal traction was used for tillage operations. The ridges were made by a ridger (then tied after 30 days) and ripping by "Houe manga". The conventional tillage consisted of disc ploughing and harrowing. For no - till plot, herbicide was sprayed before planting. Improved sorghum (*Sorghum bicolor L. Moench*) variety SARIASO 14 was used as the test crop. Six (6) seeds per hill were sown at a spacing of 80 cm x 40 cm giving a plant population of 31,350 seedlings per ha. One week after emergence, the seedlings were thinned to two plants per hill. The germination percentage was 95. The cropping system was continuous sorghum.

3.5. Crop husbandry practices

The Compost on the tilled plots was spread before tilling. Mineral fertilizers were applied in splits by side placement to their respective treatment plots two weeks after planting (WAP). For the no - till plots, compost was applied at the soil surface. For the mulching, the crop residues were chopped into 30 cm pieces and then applied after tilling. Weed control was carried out manually with hand hoe as and when necessary.

3.6. Growth parameter measured

In order to assess the effects of tillage practices and fertility management options on plant growth, sorghum plant height was measured every 30 days after sowing.

3.7. Sorghum grain and straw yield

The sorghum was harvested after four months from a delineated area of 8.4 x 2.4 m (20.16 m^2) in the middle of each treatment plot leaving the border rows. After sun drying the ears, the grain was removed and further dried to a moisture content of 13 %. The weight of the grains (yield) were taken and extrapolated to kg ha^{-1}. The harvested straw was also sun dried and weighed and the values converted to per kg ha^{-1}.

3.8. Harvest index

The harvest index (HI) was calculated as a ratio of grain yield to above ground dry matter.

$$HI = \frac{\text{Grain yield (kg/ha)}}{\text{Above dry matter (kg/ha)}}$$

3.9. Soil sampling

Prior to the commencement of the experiment, three composite soil samples (each consisting of four bulked sub-samples) were collected from each field at 0 - 10 and 10 - 20 cm depths. These soil samples were air - dried, sieved through a 0.5 and 2 mm mesh and stored at room temperature pending soil physical and chemical analyses.

Soil samples were taken after harvesting during both the first and the second years of the experiment. For aggregate stability tests, soil was randomly sampled during the second year at three points at 0 - 10 cm depth and mixed to obtain a composite sample from each sub-plot. The dried samples (water content < 0.04 cm^3/cm^3) were stored in plastic boxes in the laboratory until analysis.

For the available nitrogen monitoring during the cropping season, soil samples were taken from each plot at 0 - 20 cm and 20 - 40 cm depth at four different times (every 3 weeks from the 30^{th} day after sowing). The samples were transported in a cooled box from the field to the laboratory and stored in a freezer.

3.10. Determination of soil physical parameters

3.10.1. Particle size analysis

The particle size distribution was measured using the modified procedure described by Dewis and Freitas (1970). The sand fraction was determined by a nest of appropriate sieves (1.0, 0.5, 0.25, 0.1 mm) while silt and clay content was determined by the hydrometer method.

3.10.1.1. Procedure for sand fractions

A 50 g sample of < 2 mm, air - dry sample was dispersed with a sodium hexametaphosphate (calgon) solution, and mechanically shaken for 20 minutes. The sand fraction was removed from the suspension by wet sieving and then fractionated by dry sieving. To do this, 0.05 mm sieve was placed over a funnel and 1litre cylinder arrangement. The dispersed soil suspension was passed through a sieve, which retained the total sand fraction. The sieve was drained and placed on a watch glass, then dried in an oven for 30 - 60 minutes. After oven drying the weight was taken and the dry total sand fraction was transferred to a set of sieves (1.0, 0.5, 0.25, 0.1 mm) and a receiver. This was agitated for 15 minutes with the aid of a mechanical shaker. The finest fraction (very fine sand) was transferred to the original small tared basin and weighed. The fine sand fraction was added and weighed. This process of weighing was followed consecutively for the medium sand, coarse sand and very coarse sand fractions.

Calculations

% total sand $= 100\frac{Y}{M}$

Very fine sand $= 100\frac{A}{M}$

Fine sand $= 100\frac{B-A}{M}$

Medium sand $= 100\frac{C-B}{M}$

Coarse sand $= 100\frac{D-C}{M}$

Very coarse sand $= 100\frac{Y-D}{M}$

where,

M = weight of the air - dried soil (g).

Y = weight of the total sand (g).

A = weight of the sand fraction 50 – 100 micron (g)

B = weight of the sand fraction 50 – 250 micron (g)

C = weight of the sand fraction 50 – 500 micron (g)

D = weight of the sand fraction 50 – 1000 micron (g)

3.10.1.2. Hydrometer method for the silt and clay fractions

The clay and fine silt fractions were determined using the suspension remaining from the wet sieving process using the hydrometer method as outlined by Anderson and Ingram (1993). The dispersed sample collected in a cylinder was made up to 1litre. The mixture was inverted several times until all soil particles were in suspension. The cylinder was placed on a flat surface and the time noted. The suspension was allowed to stand for 3 hours at which the hydrometer and temperature readings were taken as shown in plate 6. This reading indicates the percentage clay. The percentage of silt was determined by difference.

Calculations

% Clay = [H + 0.2 (T – 20) – 2.0] x 2

% Silt = 100 – (% sand + clay)

where,

H = Hydrometer reading at 3 hours

T = Temperature at 3 hours in degree Celsius.

0.2 (T – 20) = Temperature correction to be added to hydrometer reading

- 2.0 = Salt correction to be added to hydrometer reading

3.10.2. Bulk density measurement

The bulk density was determined 45 days after planting at 10 cm depth using the core method. A 400 cm^3 cylinder was used in taking the core samples. These were dried at 105 °C to constant weight for 48 hours and weighed. The bulk density (ρ_b) was calculated as:

$$\rho b = \frac{Ms}{Vt}$$

where:

Ms = Oven dry weight of soil (g)

Vt = total volume of cylinder (cm^3)

3.10.3. Soil porosity

Soil porosity (f) was calculated using bulk density and particle density according to the following equation:

$$\% f = (1 - \frac{\rho b}{\rho s}) \times 100$$

where:

ρb = soil bulk density

ρs = particle density; for the mineral Ferric Lixisol, a value of 2.6 Mg m^{-3} was used.

3.10.4. Aeration porosity

Aeration porosity (fa) was calculated as:

$$fa = f - \theta v$$

where:

f = porosity

Θv = volumetric water content

3.10.5. Soil moisture measurement

3.10.5.1. Gravimetric water content measurement

A 10 g soil was oven dried at 105^0 C to a constant weight for 48 h. The gravimetric water content (Ѳm) was calculated as:

$$\theta m = \frac{Mw}{Ms}$$

where:

Mw = weight of water in soil sample

Ms = dry weight of the soil sample

3.10.5.2. Volumetric water content

The volumetric water content (Ѳv) was calculated as:

$$\theta v = \theta m \times \frac{\rho b}{\rho w}$$

where:

ρ_b= soil bulk density

ρ_w= density of water

3.10.5.3. Time domain reflectometry (TDR) of soil water content determination

Before the establishment of the experiment, 60 cm deep access tubes were placed in each sub - plot. In tied ridging plots, the access tubes were installed on the ridges while in ripping plots they were installed between the ripping lines. Soil moisture was measured with the time domain reflectometry method (TDR – TIME - FM) (Figure 3.6) at depths of 0 - 20, 20 - 40, and 40 - 60 cm. The TDR system relates volumetric soil water content to the dielectric constant of the soil (Topp *et al.*, 1980).

The TDR -TRIME - FM was calibrated from gravimetric sampling at early rainy season. Weekly readings, three per sampling point, were taken from July to November.

Figure 3.5 : Soil moisture monitoring

3.10.6. Measurement of infiltration

Infiltration tests were performed in the second year of the study, after harvesting (December). In each plot infiltration measurements were carried out in situ, using a tension disc infiltrometer (Plexiglas infiltrometer model SW 080 B, Paris, France). In tied ridging plots, the infiltration measurement was done on the ridges while for the ripping plots it was done between the ripping lines. The tensions, h = -10 cm, -5 cm, and h = 0 cm water were applied at the soil - disc interface, at the same place for the three pressure heads. Two replications were performed per plot. For sorptivity determination, a reading was taken at h = 0 cm.

3.10.7. Determination of hydraulic conductivity

The hydraulic conductivity was determined from the infiltration measurements using the expression (Wooding, 1968):

$$Q = K\left[1 + \frac{4}{\pi r \alpha}\right] \qquad (1)$$

where, r (cm) is the disk radius, Q (cm h^{-1}) is the constant infiltration rate, K (cm h^{-1}) is the hydraulic conductivity, and α is a constant dependent on soil porosity.

Assuming an exponential correlation between conductivity and the pressure head gives (Gardner, 1958):

$$K(h) = Ks \exp(\alpha h) \qquad (2)$$

Where, K_s is the saturated hydraulic conductivity, K(h) - the hydraulic conductivity at a given pressure head and h is the applied pressure head. To be able to calculate K_s, at least two pressure heads are needed. For two heads pressure h1 and h2,

$$Q(h1) = Ks\,\mathrm{e}^{(\alpha h1)}\left[1 + \frac{4}{\pi r \alpha}\right] \qquad (3)$$

$$Q(h2) = Ks\,\mathrm{e}^{(\alpha h2)}\left[1 + \frac{4}{\pi r \alpha}\right] \qquad (4)$$

From equations (3) and (4), α is calculated as,

$$\alpha = \frac{\ln(\frac{Q1}{Q2})}{(h1 - h2)} \qquad (5)$$

From α, h_1 and h_2 fixed and Q measured it was possible to calculate Ks using equations (3) and (4).

$$Ks = \frac{\alpha}{r}\exp(-\alpha h1)\frac{Q(h1)}{Q} \quad (6)$$

3.10.8. Sorptivity determination

Soil sorptivity (S) is a term defined by Philip (1975) as soil hydraulic property which describes the movement of water in the soil at early stages of infiltration by capillary action. The infiltration is governed by equation (7). The first term of the equation is the gravity free absorption of water into the soil due to capillary and adhesive forces to soil solid. The second term of the equation represents the infiltration due to the gravity when the sol wets up. At early stage of infiltration, the second term is null and the equation is reduced to equation (8). The sorptivity was determined from equation (9).

$$I=St^{1/2} + At \quad (7)$$

$$I=St^{1/2} \quad (8)$$

$$S = \frac{I}{\sqrt{t}} \quad (9)$$

where I is the cumulative infiltration (mm), S the sorptivity (mm/s$^{1/2}$), t is the time (s) and A is the empirical constant of the soil related to unsaturated hydraulic conductivity.

3.10.9. Determination of hydraulically functioning pore size (λm)

Angulo - Jaramillo *et al*. (2000) defined the hydraulically functioning pore size, λm for given infiltration parameter as:

$$\lambda m = \frac{\sigma\alpha}{\rho g} \tag{11}$$

where α is a constant dependent on soil porosity, **σ** is the surface tension of water (7.2×10^{-2} N.s.m^{-2}), ρ the density of water (1000 kg m^{-3}) and g the gravitational constant (9.81 m s^{-1})

3.10.10. Aggregate stability measurement

Aggregates stability of the soil (sandy loam) was measured during the second year of the experiment using the wet sieving method (Kemper and Rosenau, 1986). The stability of macro-aggregates and micro-aggregates in the sizes ranges from 0.25 and 2 mm, and 0.05 and 0.25 mm.

Three grams of air-dried soil samples were placed in tubes equipped with sieves of 250 microns (μm) mesh or 50 (μm) microns (depending on the case) and immersed in distilled water. The apparatus uses an electric motor to dunk sieves up-and-down in distilled water. After 3 minutes of sieving, the mass of soil remaining on the sieve was collected, dried at 40 °C and weighed. It was then subjected to a destruction of the organic material using hydrogen peroxide and to dispersion with sodium hexametaphosphate (HMP). The sample was then rinsed with water to remove the minerals leaving the sand which was reweighed after drying. The content of water - stable aggregates (Ag) was expressed as a percentage of total soil sample weight by the formula:

$$\text{Ag}\ (\%) = \frac{(\text{total Ag} - \text{sand})}{(\text{test sample} - \text{sand})}$$

3.11. Chemical analysis

3.11.1. Soil pH

The pH of the soil was determined with a pH meter using soil: water ratio of 1:2.5. Twenty grams soil sample was weighed into a beaker. To do this 50 mL distilled water was added and the suspension stirred continuously for 60 minutes and allowed to stand for 15 minutes. After calibrating the pH meter with buffer solutions of pH 4.0 and 7.0, the pH was read by immersing the electrode into the soil suspension.

3.11.2. Organic carbon

The modified Walkley and Black procedure as described by Nelson and Summers (1982) was used in the determination of organic carbon. One gram of soil sample was weighed into an Erlenmeyer flask. A reference sample and a blank were included. Ten millilitres of 1.0 *N* (0.1667 *M*) potassium dichromate was added to the sample and the blank. Concentrated sulphuric acid (20 mL) was carefully added to the soil from a measuring cylinder, swirled and allowed to stand for 30 minutes in a fume cupboard. Distilled water (250 mL) and 10 mL concentrated orthophosphoric acid were added and allowed to cool. A diphenylamine indicator (1 mL) was then added and titrated with 1.0 M ferrous sulphate solution.

The organic carbon content was calculated from equation:

$$Carbon\,(\%) = \frac{(m.e\; K_2Cr_2O_7 - m.e.FeSO_4)\times(1.32)\times 0.003\times 100}{wt}$$

where:

m.e = normality of solution x mL of solution used

0.003 = m.e. wt of C in grams (12/4000)

1.32= correction factor

wt= weight of oven-dried sample in gram

3.11.3. Total nitrogen, phosphorus and potassium in soils

To determine the total soil nitrogen (N), phosphorus (P) and potassium (K), the samples were first mineralized using H_2SO_4-Se-H_2O_2 (Houba *et al.*, 1997).

A sample of 0.3 g oven dried (70 °C) soil (0.25 mm mesh) was put into a labelled dry and clean digestion tube. Five milligrams digestion mixture was added to each tube and the reagent blanks for each batch of samples. The samples were digested at 110 °C for 1 hour. The solution was removed, cooled and three successive 1 mL portions of hydrogen peroxide were added. The temperature was raised to 330°C to continue heating. About 25 mL of distilled water was added and mixed well until no more sediment dissolved. The solution was allowed to cool and made up to 50 mL with distilled water.

The total N and total P contents in the digested solution were measured using an automatic colorimeter (Skalar SANplus Segmented flow analyzer, Model 4000-02, Breda, Holland). Total N was determined using a modified Bethelot reaction (Krom, 1980), and total P following the method of Murphy & Riley (Murphy and Riley, 1962). Total K was determined using a flame photometer (Jencons PFP 7, Jenway LTD, Felsted, England).

3.11.4. Available nitrogen (NH_4^+ and NO_3^-)

Soil inorganic nitrogen content was analysed using the Skalar Methods. The automated procedure for determination of Nitrate + Nitrite was based on the cadmium reduction method. The soil sample was shaken with 1.0 *M* potassium chloride solution in a ratio of 1: 10 for one hour. The extract was obtained after filtration. The soil extract was then passed through a column containing granulated copper-cadmium to reduce the nitrate to nitrite. The nitrite (originally present plus reduced nitrate) was determined by diazoting with sulphanilamide and coupling with α-naphthylethylenediamine dihydrochloride to form a highly colored azo which was measured at 540 nm.

3.11.5. Exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 *M* ammonium acetate extract (Black, 1986) and the exchangeable acidity (hydrogen and aluminium) was determined in 1.0 M KCl extract (Page *et al*., 1982).

3.11.6. Exchangeable bases extraction

A 5 g soil sample was weighed into a leaching tube and leached with 100 mL buffered 1.0 *M* ammonium acetate solution at pH 7.

3.11.7. Determination of calcium and magnesium

To analyse for calcium and magnesium, a 25 mL aliquot of the extract was transferred into an Erlenmeyer flask. To this were added 1 mL portion of hydroxylamine hydrochloride, 1 mL of 2.0% potassium cyanide, 1 mL of 2.0 % potassium ferrocyanide, 10 mL ethanolamine buffer and 0.2 mL Eriochrome Black T solution. The solution was titrated with 0.01 *M* EDTA (ethylene diaminetetraacetic acid) to a pure turquoise blue colour.

3.11.8. Determination of calcium only

A 25 ml aliquot of the extract was transferred into a 250 mL Erlenmeyer flask and the volume made up to 50 mL with distilled water. Following this, were added 1 mL hydroxylamine, 1 mL of 2.0% potassium cyanide and 1 mL of 2.0% potassium ferrocyanide solution. After a few minutes, 5 mL of 8.0 *M* potassium hydroxide solution and a spatula of murexide indicator were added. The resultant solution was titrated with 0.01 *M* EDTA solution to a pure blue colour.

Calculation:

The concentrations of calcium + magnesium or calcium were calculated using the equation:

$$Ca + Mg \text{ (or Ca) (cmol/kg)} = \frac{0.01 \times (\text{Va - Vb}) \times 100}{w}$$

where:

w = weight (g) of air – dried soil used

Va = mL of 0.01 *M* EDTA used in sample titration

Vb = mL of 0.01 *M* EDTA used in blank titration

0.01 = concentration of EDTA

3.11.9. Determination of exchangeable potassium and sodium

Potassium (K) and sodium (Na) in the leachate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg L^{-1} K and Na solutions to 100 mg L^{-1}. In doing this, 25 mL portion of each solution was taken into 250 mL volumetric flask and made up to the volume with distilled water. Portions of 0, 5, 10, 15, 20 mL of the 100 mg L^{-1} standard solution were put into 200 ml volumetric flasks. One hundred millilitres of 1.0 *M* NH_4OAc solution was added to each flask and made to the volume with distilled water. This resulted in standard series of 0, 2.5, 5.0, 7.5, 10 mg L^{-1} for K and Na. Potassium and sodium were measured directly in the leachate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively

Calculation:

$$Exchangeable\ \mathrm{K\ (cmol/kg)} = \frac{(\mathrm{a - b}) \times 250 \times mcf}{10 \times 39.1 \times w}$$

$$Exchangeable\ \mathrm{Na\ (cmol/kg)} = \frac{(\mathrm{a - b}) \times 250 \times mcf}{10 \times 23 \times w}$$

where:

a = mg L^{-1} K or Na in the diluted sample percolate

b = mg L^{-1} K or Na in the diluted blank percolate

w = weight (g) of air- dried sample

mcf = moisture correcting factor

3.11.10. Determination of exchangeable acidity (Al^{3+} and H^{+})

The soil sample was extracted with unbuffered 1.0 *M* KCl solution. Ten grams of soil sample was weighed into a 200 mL plastic bottle and 50 ml of 1.0 *M* KCl solution added. The mixture was shaken on a reciprocating shaker for 2 hours and filtered. An aliquot of 25 mL of the extract was pipetted into a 250 mL Erlenmeyer flask and 4-5 drops of phenolphthalein indicator solution added. The solution was titrated with 0.025 *N* NaOH until the colour just turned permanently pink. A blank was also included in the titration.

Calculation:

$$\textbf{Exchangeable acidity (cmol/kg soil)} = \frac{\mathbf{(a - b)\ x\ M\ x\ 2\ x\ 100\ x\ mcf}}{\mathbf{10\ x\ 23\ \ x\ w}}$$

Where:

a = mL NaOH used to titrate with sample

b = mL NaOH used to titrate with blank

M = molarity of NaOH solution

w = weight (g) of air- dried sample

2 = 50/25 (filtrates/ pipetted volume)

mcf = moisture correcting factor (100 + % moisture)/100

3.11.11. Effective cation exchange capacity (ECEC)

This was calculated by summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and exchangeable acidity (Al^{3+} and H^{+}).

3.11.12. Percentage base saturation

This was calculated from the sum of exchangeable bases as a percentage of the ECEC of the soil.

3.11.13. Soil stability index

Particle size distribution and soil organic carbon (SOC) content were used to calculate the structural stability index (StI) as suggested by Pieri (1992), which expresses the risk for soil structural degradation associated with SOC depletion:

$$StI = \frac{1.72 \times SOC}{clay + silt} \times 100$$

where, SOC is the soil organic carbon content (%) and clay + silt is the combined clay and silt content of the soil (%).

StI < 5% indicates a structurally degraded soil; 5 % < StI > 7 % indicates a high risk of soil structural degradation; 7 % < StI > 9 % indicates a low risk of soil structural degradation; and StI > 9 % indicates sufficient SOC to maintain the structural stability.

3.12. Nutrient uptake

Nutrient uptake was calculated as product of nutrient concentration in grain or straw multiplied by the yield.

Nutrient uptake = Nutrient concentration in grain/straw x yield

3.13. Nitrogen, phosphorus and potassium utilization efficiency (NUE)

The Nutrient Utilization Efficiency (NUE) was calculated as a ratio of yield (grain or biomass) to the total nutrient absorbed (Christianson and Vlek, 1991) as:

$$NUE = \frac{Yield}{Total\ \text{nutrient absorbed}}\ kg/kg$$

3.16 Characterization of organic materials (compost, millet straw and plant nutrients)

The crop residues and compost used in the experiment were characterized to determine their nutrient composition before application. Parameters such as organic carbon, total nitrogen, phosphorus and potassium were determined and used to assess the quality of the organic materials. Nutrient uptake (N, P and K) in plant biomass and grain yield were also determined.

3.16.1 Organic carbon

Organic carbon content of both compost and crop residues were determined using the dichromate-acid oxidation method. Ten millilitres (10 ml) each of concentrated sulphuric acid, 0.5 *N* potassium dichromate solution and concentrated orthophosphoric acid were added to 0.05 g of sample in Erlenmeyer flask. The solution was allowed to stand for 30 minutes after addition of distilled water. It was then back titrated with 0.5 *N* ferrous sulphate solution with diphenylamine indicator. The organic carbon content was calculated from equation:

$$Carbon\ (\%) = \frac{N \times (a-b) \times 3 \times 0.001 \times 100 \times 1.3}{w}$$

where:

N = normality of the ferrous sulphate

a= mL ferrous sulphate solution required for sample titration

b= mL ferrous sulphate solution required for blank titration

w= weight of oven-dried sample in gram

3 = equivalent weight of carbon

1.3= compensation factor allowing for incomplete combustion

3.16.2 Total nitrogen, phosphorus, potassium

The crop residues, compost and grain total nitrogen (N), phosphorus (P), potassium (K) and pH were determined using the same procedure for soil sample analysis.

3.17 Statistical analysis

Mixed models analysis was conducted using pro Genstat package (version 9.2) for the sorghum growth and yield data, structural stability index and for the repeated measurement data. When statistically significant effect was detected, the standard error of the difference of means (sed) was used for evaluating mean separations. Statistical significance was determined at a chi^2 probability of 0.05.

The soil water stock, soil organic carbon content, pH, N, P and K contents were analyzed using analysis of variance (ANOVA) and the means separation performed using the least significant difference (lsd) method at 5 % of probability.

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

This section deals with the results of the study and discussion. The treatment comprised the following tillage and soil amendments:

1- Tillage

- zero
- Ripping,
- Tied-ridging
- Conventional

2- Soil amendments

- No amendment,
- Compost
- NPK + urea,
- Compost + NPK + urea
- Mulch

4.1. Initial physico-chemical properties of the soil before start of experiment

The initial characteristics of the soil were determined to facilitate assessment of the impact of the imposed treatments. The results are presented in Table 4.1. The soil had low and very low organic carbon, nitrogen and phosphorus contents respectively and was slightly acid with a high base saturation, medium exchangeable calcium and magnesium contents. The exchangeable potassium content was also low.

As expected, nutrient concentration was high in the topsoil (0 - 10 cm) than in the subsoil (10-20 cm). Organic carbon, total N, P and K were 19, 50, 27 and 37% higher in the topsoil, respectively than in the subsoil. However the CEC of the subsoil was about 22% higher than that of the topsoil. The exchangeable Na contents of both the topsoil and the subsoil were comparable even though the former had a slightly higher Na content than the latter. The fertility status of the soil was basically low indicating the need for appropriate measures of soil management and soil fertility improvement.

The soil was Lixisol with a sandy loam texture consisting of 66.3% sand, 26.9% of silt and 6.8% clay at 0 - 10 cm depth. The bulk density was 1.64 at 0 - 10 cm depth.

Table 4.1: Physico - chemical characteristics of the soil at the research site

Soil depth (cm)	**0-10**	**10-20**
Organic carbon (%)	1.06	0.89
pH (1 :2.5 H_2O)	6.00	5.70
Total nitrogen (%)	0.06	0.04
Total phosphorus (mg kg^{-1})	312.17	246.67
Total potassium (mg kg^{-1})	665.17	911.03
Exchangleable bases (cmol kg^{-1})		
Calcium (Ca^{2+})	4.59	3.03
Magnesium (Mg^{2+})	0.96	0.75
Potassium (K^{+})	0.15	0.13
Sodium (Na^{+})	0.10	0.09
Cation Exchange Capacity (CEC) (cmol kg^{-1})	6.24	7.60
Sum of Anions (S) (cmol kg^{-1})	5.80	4.00
Saturation rate (S/CEC) (%)	92.67	56.33
Bulk density (cm^3 g^{-1})	1.64	1.62
Sand (%)	66.30	65.00
Silt (%)	26.90	26.10
Clay (%)	6.80	8.90

4.2. Initial chemical characteristics of the compost and sorghum straw

The initial chemical composition of the compost and sorghum straw used as mulch materials are presented in Table 4.2. Comparatively, the straw had higher organic carbon content than that of the compost. Specifically, the organic carbon content of the straw was more than two times higher than that of the compost. However, the total N content of the compost was 159 % higher than N content of the straw. The total P contents of the two materials were comparable with the straw recording slightly higher P content than the compost. The compost was of higher quality because of its lower C: N ratio of 19. The straw material was of low quality with a very high CN ratio of 135.

Table 4.2: Chemical characteristics of compost and sorghum straw

Organic materials	**Organic Carbon (%)**	**Total N (%)**	**C/N**	**Total P ($g\ kg^{-1}$)**	**Total K ($g\ kg^{-1}$)**
Compost	19.05	1.01	18.82	2.85	12.1
Straw	53.83	0.39	135.41	2.92	15.9

4.3. Impact of tillage and soil amendments on soil physical properties

4.3.1. Bulk density, porosity and structural stability

4.3.1.1. Results

The mixed model analysis (Tables 4.3 - 4.5) showed tillage to significantly ($P<0.05$) affect the magnitude of bulk density and porosity but not aggregate stability. Soil amendments and their interaction, however, did not significantly influence the latter parameters.

The mean values of bulk density and porosity at the 0 - 10 cm depth as affected by tillage (Table 4.3) ranged from 1.58 to 1.66 Mg m^{-3} with a decreasing trend of zero > Ripping> tied-ridging> conventional tillage. A part from the differences in the bulk density of the former two tillage practices and that of the conventional tillage which were significant, all other differences were not significant. Conventional tillage recorded the lowest bulk density.

As bulk density increased, total and aeration porosities decreased. Total porosity (Table 4.3), ranging from 36.04 to 39.00 %, followed the converse trend of the bulk density. The conventional tillage had the highest total porosity among all the tillage practices with the differences being significant as those between tied-ridging versus Zero tillage and Ripping. The total porosity of the latter two treatments was not significantly different.

The mean values of the bulk density, total porosity and aeration porosity under the various soil amendments (Table 4.4). Though no significant, ranged from 1.62 to 1.64 Mg m^{-3}, 36.59 to 37.62% and 28.51 to 30.44% respectively. The impact was in a decreasing order of Compost + NPK + Urea = NPK + Urea > Control = compost = Mulch for bulk density, Compost > Mulch > Control > Compost + Urea + NPK > Urea + NPK for total porosity and Compost > Control > Urea + NPK > Compost + Urea + NPK > Mulch for aeration porosity.

Bulk density and total porosity are often used as indicators of the degree of soil compaction or soil structure degradation. In this study, the impact of the soil tillage and amendments on soil aggregate stability was assessed by Pieri's (1992) soil structure degradation index (StI). The greater the value of StI, the better the aggregate stability with values < 5 signifying degraded soil structure. The mean values of StI under the tillage practices (Table 4.5) ranged from 4.4 to 4.8 in decreasing order of Zero tillage > Ripping = Tied-ridging > Conventional tillage.

The mean StI under soil amendments (Table 4.5) varied from 4.2 and 5.1 in the order of Compost + NPK + Urea > compost > NPK + Urea > Control> Mulch.

Table 4.3: Effect of tillage practices on soil bulk density, porosity and aeration porosity at 0 - 10 cm depth

Tillage practices	Bulk Density (Mg m^{-3})	Porosity (%)	Aeration porosity (%)
Zero tillage	1.66	36.04	27.14
Ripping	1.65	36.42	29.51
Tied - ridging	1.62	37.53	27.93
Conventional tillage	1.58	39.00	31.09
Chi^2 probability	0.016	0.02	0.03
Sed	0.05	1.02	1.46

Table 4.4: Effect of fertility management options on soil bulk density, porosity and aeration porosity at 0-10 cm depth

Fertility management	Bulk Density (Mg m^{-3})	Porosity (%)	Aeration porosity (%)
Control	1.62	37.59	29.44
Compost	1.62	37.64	30.44
NPK + Urea	1.64	36.59	29.40
Compost + NPK + Urea	1.64	36.81	28.80
Mulch	1.62	37.62	28.51
Chi probability	0.81	0.81	0.23
Sed	0.03	1.14	1.63

Table 4.5: Mixed model analysis of soil of Pieri soil strutural stability index

Fixed term	Wald statistic	d.f.	Wald/d.f.	chi pr
Tillage	3.28	3	1.09	0.351
Fertility	2.75	4	0.69	0.601
Tillage x Fertility	15.68	12	1.31	0.206

Tillage Practices	StI	Fertility management	StI
Zero tillage	4.8	Control	4.4
Ripping	4.7	Compost	4.9
Tied Ridging	4.7	NPK + Urea	4.8
Conventional tillage	4.4	Mulch	4.2
		Compost+NPK+Urea	5.1
Sed	0.8	Sed	0.5

4.3.1.2. Discussion

The results showed that bulk density at the 0 - 10 cm depth of the experimental field, measured 45 days after the imposition of the tillage treatments, were generally high as indicated by the value of 1.66 Mg m^{-3} under Zero tillage. The figure falls within the bulk density of sandy loams with a risk for root restriction (Landon, 1991). Under such circumstances, some form of tillage is required to loosen the soil to provide a favourable bio - physical condition for seedling emergence, crop growth and yield. Thus, all tillage beyond Zero, recorded lower bulk densities but more significantly under conventional tillage, followed by tied-ridging. Similar observations of higher bulk densities under Zero tillage than conventional tillage have been reported (Baffoe-Bonnie and Quansah, 1975; Ouattara, 1994; Xu and Mermoud, 2001; Dam *et al.*, 2005; Zida, 2011). Baffoe-Bonnie and Quansah (1975) further observed that soils tend to have the lowest bulk density and highest total porosity immediately after ploughing.

By pulverizing the soil with changes in soil structure, the loosening of the top 10 cm of the soil by tillage, particularly the conventional and Tied - ridging reduced the mass of soil per unit volume of the soil with a consequent reduction in bulk density. Correspondingly, total and aeration porosities increased under these tillage practices than the Zero tillage. The 5% lower bulk density of the Conventional than Zero tillage thus resulted in an increase of 8% and 15% in total porosity and aeration porosity, respectively. The latter porosity is therefore more sensitive to soil compaction than the former. These impacts need to be considered in the use of bulk density, total and aeration porosities as soil quality indicators affecting soil structure under various tillage practices and their implications for soil functions and processes (Hou *et al*., 2012). They exert variable impacts, negative or positive, on infiltration and permeability, rooting proliferation and depth, water storage and activity of microorganisms, which influence soil productivity (Landon, 1991; Hou *et al*., 2012).

It is, however, worthy to note that the loosening of the soil by the Conventional and Tied - ridging resulting in lower bulk density and increased total and aeration porosities may be short - lived. They rapidly undergo changes and revert to their original or higher values within the cropping season due mainly to soil settling and packing under the impact forces of rainfall and between seasons due to continuous tillage. The former reason underscores the observation of Baffoe - Bonnie and Quansah (1975) that the initial low bulk density and high total porosity under plough - plant early in the cropping season increased by the end of the season. The latter reason may account for the often reported higher bulk density under Conventional tillage than Zero tillage (Roscoe and Buurman, 2003). Lessons drawn from these earlier studies may inform the development of appropriate suitable land management strategies for the future cultivation of the soils in the experimental area.

The major concern with tillage arises when it becomes intensive and continuous by which the natural soil structure is destroyed to significantly alter soil functions and cause erosion (Blanco and Lal, 2008). As observed in this study, the generally low structure stability of the experimental soil, using that of the Zero tillage as the base value, was further reduced by Conventional tillage. This may be due to the generally observed rapid decomposition of organic matter and loss of carbon under Conventional tillage as well as the selective removal of soil fines particles, particularly clay and silt by both wind and water erosion over the two seasons (Quansah and Baffoe-Bonnie, 1981 and Ouattara, 1994). Importance and positive role of organic matter and clay in soil structure formation and aggregate stability are well documented by Ouattara (1994) and Le Bissonnais (1996). As indicated in subsequent sections, although the differences in organic matter content under the various tillage treatments were not significant, the conventional tillage consistently recorded the lowest level of soil organic carbon.

On the other hand, all soil amendments incorporating compost as a constituent tended to increase aggregate stability. This may be ascribed to the higher soil organic carbon under the compost treatments than the other soil amendments as indicated in section 4.4.2.

Continuous monitoring of bulk density, porosity and aggregate stability under future tillage of the soil and application of soil amendments would be necessary to avert the adverse impact of tillage and choice of appropriate land management practices for sustained sorghum crop growth and yield in the south Sudan agro-ecological zone.

4.3.2. The impact of tillage and soil amendments on soil infiltration, field saturated hydraulic conductivity, sorptivity and pore sizes

4.3.2.1. Results

Mixed model analysis (Tables 4.6 and 4.7) showed tillage and soil amendments to significantly influence infiltration rate and saturated hydraulic conduction. Sorptivity was significantly affected by soil amendments but not tillage.

Infiltration rate (Table 4.6) varied between 0.83 and 1.15 cm h^{-1} in the order of Ripping > Conventional tillage > Tied ridging > Zero tillage. Apart from the difference in infiltration rate between Ripping and conventional tillage, which was not significant, all other differences among the tillage treatments were significant with the Zero recording the least rate of infiltration. Although all tillage beyond Zero recorded infiltration rates > 1 cm h^{-1}, infiltration under all tillage practices fell within the moderately slow category (0.5 – 2. cm h^{-1}) by Landon's (1991) guidelines.

The impact of tillage on field saturated hydraulic conductivity (Ks) showed that Ks range from 7.8 to 37.8 cm h^{-1} in a decreasing order of Tied ridging > Zero tillage > Conventional tillage > Ripping (Table 4.6). Ks varied from moderately rapid (6-8 cm h^{-1}) under ripping, through rapid (8 – 12 cm h^{-1}) under Conventional, to very rapid (>12 cm h^{-1}) under Zero and Tied ridging. In all cases, the differences in Ks among the treatments were significant except that between Conventional tillage and Tied ridging.

The sorptivity (Table 4.6) ranged from 0.610 to 0.669 mm $S^{1/2}$ for the Zero tillage and Ripping respectively with no significant differences between the tillage practices. All the tillage treatments recorded greater sorptivity than the Zero tillage with the percentage increment being 3, 7 and 10 under Tied ridging, Conventional and Ripping respectively.

Tillage practices also significantly influenced hydraulically functioning pores, designated as λm (μm). The pore sizes varied from 6 to 105 μm (0.006 to 0.105 mm) under Tied ridging and Ripping respectively with a trend of Tied ridging > Zero tillage > Conventional tillage > Ripping. The difference in the magnitude of pore size of the latter two tillage treatments was not significant. All other differences among the remaining tillage treatments were significant. The pore diameter categorization (Landon, 1991) of tillage practices were coarse (macro) pores (> 100 μm) for Tied-ridging, medium (meso) pores (30 – 100 μm) for Zero tillage, fine (micro) pore (< 30 μm) for Ripping and Conventional tillage. These pores have significant implications for water movement, storage and aeration which are discussed in subsequent sections.

The mean infiltration rate, as influenced by soil amendments, ranged from 0.842 to 1.163 cm h^{-1} under compost + NPK + urea and NPK + urea respectively (Table 4.7). Infiltration rate was moderately slow under all the soil amendments. Infiltration rate was in the order of NPK + urea > Control > Compost > Mulch > Compost + NPK + urea. Neither differences among the three latter nor the former two amendments were significant. However, between these two groups, the differences were significant. The addition of compost to NPK + Urea decreased infiltration rate of the latter amendment by 28% but it still remained moderately slow.

The saturated hydraulic conductivity (Table 4.7) varied between 6.8 and 40.4 cm h^{-1} under control and mulch respectively in the order of mulch > NPK + Urea > compost + NPK + urea > compost > control. Saturated hydraulic conductivity was moderately rapid under control, rapid under compost and very rapid under mulch, NPK + urea and compost + NPK + urea. The differences in the magnitude of hydraulic conductivity between control and compost as well as those of the compost, NPK + urea and compost + NPK + urea were not significant. All other differences were significant with mulch recording the highest Ks.

Sorptivity (Table 4.7) under the amendments was in a decreasing order of compost > control > NPK + urea > compost + NPK + urea > Mulch with values ranging from 0.535 to 0.781 mm $S^{1/2}$ for mulch and compost respectively. All the soil amendments recorded significantly greater sorptivity than the mulch. The differences between the control and compost and those between NPK + urea and compost + NPK +urea were not significant. The sorptivity under compost was significantly greater than all the other amendments.

The hydraulically functioning pores recorded under the various soil amendments ranged from 0.008 mm to 0.082 mm in an increasing order of control < compost < NPK + Urea < mulch < compost + NPK + Urea (Table 4.7). The differences were, however not significant ($P<0.05$). The pore sizes were micro under control and compost and medium (meso) under NPK + Urea, mulch and compost + NPK + Urea.

There was a positive relationship between hydraulically functioning pore diameter and soil hydraulic conductivity values with a R^2 value of 0.79 % (Figure 4.1).

Table 4.6: Soil hydraulic characteristics as affected by tillage practices

Parameters	Tillage practices					
	Zero tillage	Ripping	Tied Ridging	Conventional tillage	Chi^2 probability	SED
i (cm/h)	0.828	1.152	1.008	1.116	0.01	0.108
λm (mm)	0.034	0.006	0.105	0.012	0.04	0.037
Ks (cm h^{-1})	19.40	7.80	37.80	11.30	0.009	9.60
S mm $s^{1/2}$	0.610	0.669	0.631	0.650	0.20	0.07

λm = hydraulically functioning pore size; SED = standard error of difference of means**,** I = infiltration rate, Ks = saturated hydraulic conductivity, S = Sorptivity

Table 4.7: Soil hydraulic characteristics as affected by fertility management options

Parameters	**Fertility management options**						
	Control	**Compost**	**NPK + Urea**	**Mulch**	**Compost + NPK +Urea**	**Chi^2 pr**	**SED**
i (cm/h)	1.142	1.097	1.163	0.843	0.842	0.02	0.134
λm (mm)	0.008	0.014	0.030	0.063	0.082	0.35	0.043
Ks (cm h^{-1})	6.80	1.09	1.99	40.40	17.50	0.02	10.7
S mm $s^{1/2}$	0.758	0.781	0.637	0.535	0.614	0.008	0.08

λm = hydraulically functioning pore size; sed = standard error of difference of means**,** I = infiltration rate, Ks = saturated hydraulic conductivity, S = sorptivity

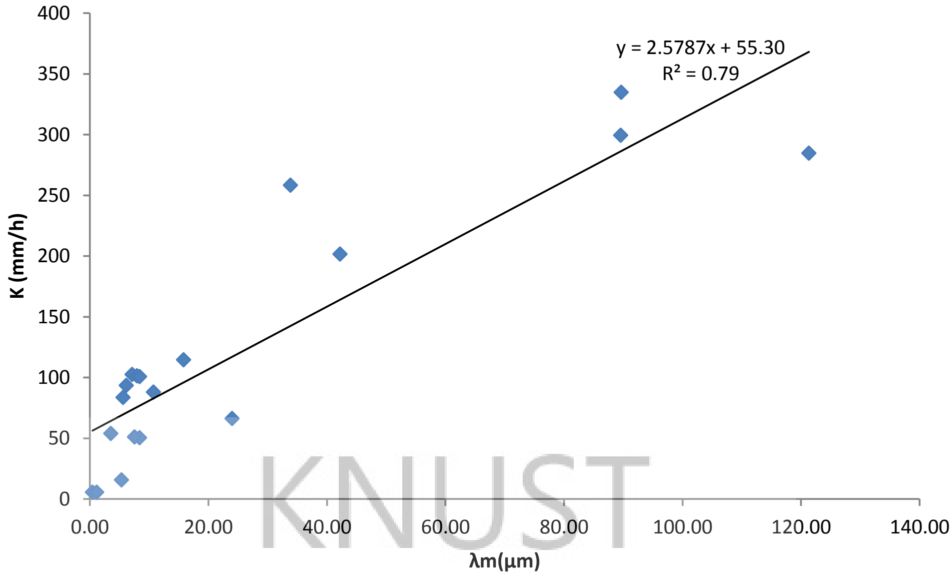

Figure 4.1 : Relationship between hydraulically functioning pore diameter and soil hydraulic conductivity values

4.3.2.2. Discussion

The growth, development and yield of crops depend on adequate supply of water at each stage. The main source of this water supply is the soil water stock mainly from rainfall in rainfed agriculture. The dependence of plants on water stored in the soil is due to the fact that plants store very little water compared to their daily requirements, which is about 60 m^3 ha^{-1} (Ehlers *et al.*, 1987).

In the Sahelian zone of Burkina Faso, where adequate water availability for plant growth is and continues to be a major constraint to crop production, there is an urgent need to make full use of the soil as a water reservoir and conductor to sustain crop growth and yield. This is even more so in the ongoing climate variability and change, the adverse impacts of which are extending to hitherto favourable agro-ecological zones, such as the south Sudan of Burkina Faso.

Available strategies to achieve this include managing the soil to take up as much water as possible for storage and insuring that the water stored is optimally used by plants for photosynthate production through transpiration. This requires reducing the non - productive evaporation from bare soil surfaces and weeds. These goals can be achieved by enhancing the soil's infiltrability (infiltration control) whilst reducing evaporation (evaporation control) through the respective use of tillage and crop residue management, particularly mulching (Ehlers *et al*., 1987).

The major physical properties of the soil affecting it water intake, storage, recharge of groundwater, onset of overland flow and deep percolation are sorptivity, infiltrability, hydraulic conductivity and porosity especially pore size distribution and pore continuity (Turner, 2006 and Ouattara, 2007). These properties measured in this study respond variably to different tillage, residue management and soil amendments. These responses, which have hitherto not received much attention, particularly in the south Sudan zone of Burkina Faso, are discussed separately but integratively to show how they act individually and together to achieve the goal of water intake and storage in the soil and their implications for water conservation for sorghum growth and yield.

Sorptivity

Sorptivity is a measure of the capacity of the soil to absorb or desorb water by capillarity without gravitational impact (Philip, 1957). It is embodies in a single parameter the influence of matrix suction and conductivity on the transient related to changes in surface wetness or suction. Sorptivity values depend on initial water content and diminish as initial moisture increases (Philip, 1957). These values therefore have meaning only in relation to initial and final moisture content (Hillel, 1998). According to Bonsu (1993), sorptivity is an important soil characteristic which governs the early stage of infiltration with significant impact on time –to-incipient ponding, defined as the transition between predonding and ponding during infiltration into unsaturated soil. The latter influences the overland flow production potential of the soil and the commencement of the sediment transport by overland flow in the erosion process.

The results of the study showed that the magnitude of sorptivity, measured at an initial soil moisture range of 0.05 – 0.10 m^3 m^{-3}, did not vary significantly among the tillage practices, except that between Ripping and Zero tillage ($P<0.05$). However, all tillage practices beyond Zero resulted in higher sorptivity with percentage increment being 3, 7 and 10 under Tied-ridging, Conventional tillage and Ripping respectively. This could be the loosening of the soil under the latter three practices which resulted in a greater total porosity than the relatively compact Zero-tilled soil (1.66 Mg ^{3}).

It is worthy to note, however that whilst total porosity is an important consideration in soil water processes such as sorptivity, infiltration, hydraulic conductivity and water storage, pore size, distribution and continuity exert the most significant impact. Yet most studies on these processes lay emphasis on total porosity to the neglect of the size determination, presumably because of the ease of measurement of the former.

The results further showed a tendency of sorptivity to decrease with increasing pore size. Thus sorpitivity of the tillage practices (Zero, Ripping and Conventional) which recorded hydraulically functioning pore sizes within the capillary pore size range (micro and meso pores) were higher than Tied-ridging which had non capillary pores (macro pores). This may be due to the greater dependence of sorptivity on matrix suction resulting from the physical affinity between water and the matrix of soil, including both the soil particle surfaces and the capillary pores than gravitational force (Hillel, 1998). Indeed this accord with Hallett's (2008) assertion that soil with larger (non-capillary) pores has lower sorptivity than that with smaller (capillary) pores. Even in the latter range, sorptivity decreased with increasing pore size micro (Ripping and Conventional) to meso (Zero) pores. The magnitude of sorptivity has important implications for time-to-incipient ponding. Higher sorptivity increases time-to-incipient ponding and delays the onset of overland flow production through affording the soil a greater contact time for water intake and storage. This decreases runoff volume and energy for sediment transport and erosion is thereby reduced. The higher sorptivity recorded under Ripping than Zero tillage implies a greater cumulative infiltration and less potential risk to runoff and erosion. This is reasonable considering that, apart from having similar residue-covered surface condition as the Zero plots, Ripping produced shallow slits with micro bunds along the edges on the contour to serve as in-situ water harvesting and conservation zones.

Sorptivity was also influenced by soil amendments. At the base value of the control plots, sorptivity was increased but not significantly by compost. However, it was significantly reduced by all the other soil amendments, and more so by mulching. The underlying reason may be due to the impact of the amendments on pore size. Whilst the compost maintained the microporosity of the control, the other amendments, especially mulching and compost + NPK + Urea increased the micro to mesopores with a consequent reduction in sorptivity as pointed out earlier. Studies of the impact of soil amendments on sorptivity are scare in the literature and would require in depth research attention to facilitate a better understanding and management of soil amendments of enhanced soil water relationships and productivity.

Infiltration

The implication of the preceding discussion is that, in rainfed agriculture, the farmers' insurance for available water for sustainable crop growth and yield is what is stored in the soil. Soil infiltrability plays a major role in this by enhancing in-situ rain water harvesting and conservation, recharging groundwater and reducing runoff and erosion (Ouattara, 2007).

Infiltration, being the process of water entry into the soil, generally downward flow through all or part of the soil surface (Hillel, 1998), is influenced by the characteristics of the soil, especially its sorptivity and hydraulic conductivity. Other factors include rainfall intensity, temperature, vegetation cover, distribution of soil moisture and availability of water at the surface (Ouattara, 2007).

As an initial entry of water into the soil, infiltration is affected by mechanical loosening of the soil and residues management (Ouattara *et al.*, 2007). Consequently, the results of the study showed tillage and soil amendments to significantly influence infiltration. All tillage practices beyond Zero significantly enhanced infiltration with Ripping and Conventional tillage recording the highest values. As observed by Ehlers *et al.* (1987) all tillage methods which increase the looseness and openness of the top soil are of benefit to soil infiltrability. In a loose soil, the voids temporarily store water and the rapidly draining pores conduct the water into deeper layers. In an open soil, the voids and macrospores remain accessible and thus play a major role in infiltration and drainage. However, on many structurally unstable loams, such as sandy loam in this study, the open structure is rapidly lost as a result of surface slaking and sealing by raindrop impact. In these circumstances the infiltrability declines rapidly.

According to Hillel (1998), the infiltration process can be viewed as a function of the intrinsic permeability of the soil and the fluidity of the penetrating liquid. The former includes sorptivity and hydraulic conductivity and the latter, density and viscosity.

The results showed infiltration to follow the same trend as sorptivity which tended to decrease with increasing hydraulically functioning pore size. This is contrary to expectation whereby infiltration increases with increasing pore size. The underlying reasons lies with the distinction between the infiltration process under saturated and unsaturated soil and non-ponding and ponding conditions. The major difference is in the hydraulic conductivity of the soil under saturated and unsaturated flow conditions.

In this study, infiltration was measured under unsaturated conditions at the tension head (h) of 0, -5 and -10 cm. In such circumstances, large pores (macropores) as recorded under Tied-ridging quickly empty and become no-conductive as the suction develops and thereby steeply decrease the initially high conductivity. On the other hand, the small pores (micro and meso pores) as recorded under Ripping, Conventional and Zero tillage, retain and conduct water even at appreciable suction, so that hydraulic conductivity does not decrease as steeply, and may even exceed that of the large pores subjected to the same suction such as that of the Tied-ridging. This presumably accounts for why the infiltration values followed the trend of Ripping > Conventional > Zero > Tied-ridging. However, as pointed out by Hillel (1998), the very opposite is often the case when saturated conditions prevail. When the soil is saturated, all the pores are water-filled and conducting. The water phase is continuous and the conductivity is maximal. Under such conditions, the most conductive soils are those in which large and continuous pores, such as that of Tied-ridging, constitute most of the pore volume, whereas the least conductive are the soils in which the pore volume consists of numerous micropores, such as those of Ripping and Conventional tillage. It is in accord with this that saturated sandy soil conducts water more rapidly than a poorly aggregated or dispersed soil (Hillel, 1998).

Field saturated hydraulic conductivity

The latter flow conditions under saturated soil relative to pore size account for reported increaded in hydraulic conductivity with increasing hydraulically functioning pore size (λm) in this study which was in the order of Tied-ridging > Zero > Conventional > Ripping. This trend shows that hydraulic conductivity was highest under the tillage treatment with macroporosity followed by that with mesoporosity and the lowest with microporosity. Similar observation has been reported by Ouattara *et al.* (2007). Mulching also significantly enhanced hydraulic conductivity by several orders of magnitude up to about five times of that under the other amendments. The activities of ants and the other burrowing organisms in creating biopores under mulching are implicated in the increase in hydraulic conductivity as observed by Zougmore *et al*. (2004). Such pores facilitate preferential flow with consequent increase in saturated hydraulic conductivity.

4.3.3. Tillage and mulching effects on soil water stock

4.3.3.1. Results

The moisture stock was measured weekly for a period of twelve weeks under the various tillage practices and depths of 0 - 30 cm, 30 – 50 cm and 0 – 50 cm (Tables 4.8 – 4.10). The response of soil moisture stock to tillage varied with time and depth of sampling. Soil moisture stock (mm) was calculated as a product of the volumetric water content and soil depth.

At the 0 - 30 cm depth (Table 4.8) soil water stock was significant among the treatments with higher values under Zero tillage than the remaining tillage practices from the third to the ninth week except the 4th week when Ripping and Tied - ridging recorded higher values of 117 and 132 mm respectively. Although the Zero tillage recorded high soil moisture for the remaining weeks, the differences among the tillage treatments were not significant. The mean weekly soil moisture averaged over the 12 week period, ranged from 44.15 to 53.66 mm under Ripping and Zero tillage respectively in an order of Zero tillage > Tied ridging> Conventional tillage > Ripping.

At the 30 – 50 cm depth (Table 4.9), soil water stock was significantly different only at the 4th and 5th weeks (peak rainfall period) with the highest water content under Tied ridging and the lowest under Conventional tillage. The mean weekly water stock over the 12 weeks period followed a trend of Tied ridging > Conventional tillage > Zero tillage > Ripping with a range between 31.78 and 43.72 mm for Ripping and Tied ridging respectively.

Cumulative soil moisture stock at 0 - 50 cm (Table 4.10) also varied significantly only at the 4th and 5th weeks with Tied ridging recording the highest. The mean weekly soil moisture stock ranked as Tied-ridging > Zero tillage > Conventional tillage > Ripping. With a range of 73.84 mm under Ripping and 86.04 mm under Tied - ridging. The statistical analysis further showed sorghum straw mulch to significantly influence soil water stock (Tables 4.11 – 4.13).

The Weekly soil moisture stock varied significantly only at the 4th and 5th weeks at the three depths of 0 - 30 cm, 30 - 50 cm and 0 - 50 cm (Tables 4.11 – 4.13). In all these cases, water stock was higher under mulching than no mulch. The same trend prevailed over the remaining weeks, except that the differences were not significant.

The mean weekly soil water stock over the 12 week period gave values for no mulch and mulch ranging from 41.66 to 44.48, 35.85 to 37.68 and 74.46 to 79.84 mm at the 0 - 30 cm, 30 - 50 cm and 0 - 50 cm respectively.

Table 4.8: Soil water stock as affected by tillage practices at 0 - 30 cm depth

Time	Soil water stock (mm)				F probability	Lsd
	Zero tillage	Ripping	Tied -ridging	Conventional tillage		
Week 1	53.07	38.31	52.23	43.80	0.30	18
Week 2	63.48	46.95	50.55	52.62	0.50	19
Week 3	60.09	45.33	41.61	45.09	0.05	15
Week 4	75.60	117.30	131.70	63.60	0.02	30
Week 5	63.00	42.30	56.70	54.90	0.04	16
Week 6	60.36	41.58	40.98	50.85	0.02	13
Week 7	59.25	41.58	37.35	51.27	0.04	15
Week 8	53.49	36.18	40.50	43.68	0.05	13
Week 9	44.46	26.67	28.11	34.92	0.04	10
Week 10	30.09	26.49	15.30	26.43	0.10	16
Week 11	35.94	27.54	25.17	29.13	0.09	9
Week 12	45.18	39.60	33.54	40.74	0.20	12
Mean	53.66	44.15	46.14	44.75	-	-

Table 4.9 : Soil water stock as affected by tillage practices at 30 - 50 cm depth

Time	Soil water stock (mm)				F probability	Lsd
	Zero tillage	Ripping	Tied Ridging	Conventional tillage		
Week 1	48.28	32.20	35.92	45.16	0.09	16
Week 2	37.98	25.40	41.42	39.00	0.19	17
Week 3	36.66	33.54	43.26	37.82	0.50	11
Week 4	50.60	101.40	138.8	45.00	0.003	36
Week 5	41.40	32.40	83.00	38.60	0.01	31
Week 6	37.58	27.98	29.70	36.98	0.20	12
Week 7	36.50	29.02	38.04	37.14	0.20	10
Week 8	33.92	23.00	29.22	34.24	0.20	12
Week 9	32.36	22.16	24.36	33.54	0.10	13
Week 10	22.48	18.24	21.28	32.70	0.10	15
Week 11	21.36	16.04	17.98	28.72	0.30	14
Week 12	24.66	20.02	21.62	29.02	0.40	9
Mean	35.31	31.78	43.72	36.49	-	-

Table 4.10 : Soil water stock as affected by tillage practices at 0 - 50 cm depth

Time	Soil water stock (mm)				F probability	Lsd
	Zero tillage	Ripping	Tied Ridging	conventional tillage		
Week 1	101.30	70.50	88.20	89.00	0.10	35
Week 2	63.50	47.00	50.60	52.60	0.19	22
Week 3	96.80	78.90	79.50	82.90	0 .50	19
Week 4	126.00	219.00	271.00	108.00	0.003	92
Week 5	104.50	74.70	139.60	93.30	0.018	39
Week 6	98.00	69.50	70.70	87.80	0.20	29
Week 7	95.80	70.60	75.40	88.40	0.20	31
Week 8	87.40	59.20	69.70	77.90	0.20	26
Week 9	76.80	48.80	52.50	68.50	0.10	30
Week 10	52.60	44.70	36.60	59.10	0.10	24
Week 11	57.30	43.60	43.10	57.80	0.30	16
Week 12	69.80	59.60	55.20	69.80	0.40	17
Mean	85.82	73.84	86.00	77.92	-	-

Table 4.11: Soil water stock as affected by mulching at 0 - 30cm depth

	Soil water stock (mm)			
Time	**Zero mulch**	**Mulching**	**F probability**	**Lsd**
Week 1	45.80	47.90	0.70	7
Week 2	51.20	55.60	0.60	6
Week 3	48.90	47.10	0.90	4
Week 4	87.30	104.40	0.03	16
Week 5	49.70	58.70	0.04	8
Week 6	46.70	50.10	0.40	8
Week 7	44.30	50.40	0.60	7
Week 8	40.60	46.30	0.60	9
Week 9	32.60	34.50	0.80	5
Week 10	22.40	26.70	0.30	6
Week 11	28.70	30.20	0.20	3
Week 12	35.50	44.00	0.04	8
Mean	41.66	44.48		

Table 4.12: Soil water stock as affected by mulching at 30 – 50 cm depth

Time	Soil water stock (mm)		F Probability	Lsd
	Zero Mulch	Mulch		
Week 1	39.54	41.24	0.60	4
Week 2	38.47	33.44	0.70	9
Week 3	36.65	38.75	0.30	5
Week 4	78.15	88.60	0.03	8
Week 5	44.85	52.85	0.04	6
Week 6	32.31	33.80	0.20	5
Week 7	35.23	35.13	0.90	4
Week 8	29.15	31.06	0.50	6
Week 9	27.20	29.00	0.60	4
Week 10	23.47	23.89	0.80	3
Week 11	21.22	20.83	0.70	4
Week 12	24.05	23.60	0.50	4
Mean	35.85	37.68		

Table 4.13: Soil water stock as affected by mulching at 0 – 50 cm depth

Time	Soil water stock (mm)		F Probability	Lsd
	Zero Mulch	mulch		
Week 1	65.37	89.10	0.60	19
Week 2	51.17	55.60	0.80	10
Week 3	83.15	85.85	0.70	8
Week 4	165.25	193.00	0,0 3	21
Week 5	94.52	111.52	0.04	16
Week 6	79.52	85.57	0.70	9
Week 7	69.77	77.35	0.60	15
Week 8	69.77	77.35	0.60	13
Week 9	59.75	63.52	0.50	18
Week 10	45.85	50.62	0.80	11
Week 11	49.92	50.97	0.80	7
Week 12	59.50	67.67	0.40	14
Mean	74.46	79.84		

4.3.3.2. Discussion

The results showed soil moisture storage under the tillage practices to vary with time of measurement relative to rainfall and the soil depth. It must be pointed out that the soil at the experimental site is shallow, about 60 cm deep which according to Hudson's (1975) classification corresponds to the effective rooting depth of sorghum, the test crop.

Sustainable sorghum production should therefore aim at soil management practices which insure optimum soil moisture storage being 100 - 130 mm m^{-1} depth (Hudson, 1975; Ehlers *et al.,* 1987).

The mean moisture storage over the 12 week – measurement within 0 - 50 cm depth ranged from 73.84 mm for Ripping to 86.04 mm under Tied ridging. These figures are greater than the expected range of 50 – 60 mm for the 50 cm depth based on

Hudson's (1975) classification. This range could be considered indicative and could be higher depending on soil structure, rainfall amount and intensity, pore size distribution, among other factors.

The mean moisture storage at 0 - 50 cm depth, although not significant, followed a trend of Tied-ridging > Zero > Conventional > Ripping. This corresponded with the trends in the magnitude of field saturated hydraulic conductivity and the hydraulically functioning pore size (λm). Increasing pore, thus enhanced saturated hydraulic conductivity, which in turn, enhanced water flow into deeper depth for storage.

At the 0 - 30 cm depth, the mean soil moisture store was higher under tillage practices with meso – to macro pores (Zero and Tied-ridging) than those with micropores (Conventional and Ripping). At this depth, the highest soil moisture stored under Zero tillage may be due to the rate of its residues in conserving moisture through reduced evaporation.

The 30 – 50 cm depth soil moisture was highest under Tied-ridging whilst Ripping recorded the least. The macrospores and the relatively higher saturated hydraulic conductivity of the former presumably allowed more water flow into deeper layers with the furrows acting as moisture conservation zones. These zones replenish depleted moisture in the ridges due to uptake by the roots in response to decreased water potential in the ridge.

The variation in soil moisture storage with time of measurement showed significant differences mainly in 4^{th} and 5^{th} week. Week 4 was the peak rainfall period in September with a drastic drop in October.

At the peak period of rain, soil moisture storage at 0 - 50 cm depth ranged from 108 mm under conventional to 219 mm under Tied-ridging respectively. Soil moisture storage was greater under Tied - ridging and Ripping than Conventional and Zero tillage. At the peak rainfall period, the retention of rain water in the basins created by Tied-ridging and the water conservation slits under Ripping allowed more contact time for water infiltration into the soil than the Zero and Conventional tillage. The peak rainfall period (4th week) was followed by rainless period of about 14 days and few rains thereafter. This period was more of soil moisture depletion presumably through transpiration and evapotranspiration. This commenced at the 5th week through to the 12th week. At the latter period, the trend in soil moisture storage has changed from Tied - ridging > Ripping > Zero > Conventional in the 4th Week to Zero = Conventional > Ripping > Tied - ridging.

The percentage moisture depleted was 80, 73, 48 and 28 under Tied - ridging, Ripping, Zero tillage and Conventional tillage respectively.

Assuming a constant rate of transpiration and insignificant deep drainage, soil moisture depletion would be mainly through evaporation. In this context, the Zero and the Conventional tillage were better practices in conserving stored moisture. The former by reducing the energy required for evaporation, temperature, the saturation deficit at the soil and residue interface and turbulent air movement at the soil surface. The latter through soil mulch produced by ploughing which breaks the continuity of the micropores in the subsoil to the surface thereby reducing moisture supply through capillary to the surface for evaporation. For the same reasons alluded to for moisture conservation under Zero tillage, mulching also improved soil moisture at both depth and time of measurement more than no-mulching plots. Favourable effects of mulching on soil water retention have been reported for the surface layer

(Duiker and Lal, 1999; Unger *et al*., 2012). Zougmoré *et al.* (2004) reported 34 - 50% reduction in soil water evaporation as a result of crop residue mulching. The significant differences were observed only at the 4th and 5th weeks.

On the sandy loom soils in the experimental area, emphasis must be placed at optimizing soil moisture storage during the peak periods of rainfall. Beyond this period, any incidence in reduced rainfall results in a drastic depletion of available soil moisture in the rooting zone for sustainable crop production.

4.4. The impact of tillage and soil amendment on soil chemical properties

4.4.1. Effect of tillage and soil amendment on pH and soil organic carbon content

4.4.1.1. Results

Table 4.14 shows the effects of soil fertility management options on soil pH**.** The pH ranged from 5.38 to 5.74 in the subsoil (10 - 20 cm) and from 5.83 to 6.34 in the topsoil (0 - 10 cm). Soil pH in the topsoil under the management options were slightly higher than values observed in the subsoil (10 - 20 cm). Application of compost consistently produced high soil pH in both soil depths than integrated application of compost and chemical fertilizer or sole applications of both. The lowest pH was observed in the control and compost + NPK + urea plots in the 0-10 cm and 10-20 cm soil depths respectively. Fertility management options significantly affected soil pH in both soil depths after the two cropping seasons.

Tillage practices did not significantly affect (P > 0.05) soil organic carbon content (SOC) during the two years of experimentation (Table 4.15). Soil organic carbon content declined under conventional tillage practice after the two year period. The decrease in SOC content from 2012 to 2013 under conventional tillage practice was up to 13 %. Similarly, soil organic carbon content decreased in 2013 over values recorded in 2012 under tied ridging. Soil organic carbon content under zero tillage remained the same in 2013 as it was observed in 2012.

Table 4.16 shows the effects of fertility management options on soil organic carbon content both at 0 - 10 cm and 10 - 20 cm depths during the two years of experimentation. Soil organic carbon content did not change considerably after the two years but decreased with depth. As expected, the topsoil (0 - 10 cm) was richer in organic carbon than the sub soil (10 - 20 cm). The soil organic carbon content ranged from 0.97 % to 1.22 % for 0 - 10 cm depth and 0.72 % to 0.93 % for 10 - 20 cm depth. In both years of the study, the fertility management options significantly affected the SOC content of the top soil (0 - 10 cm depth) but not the subsoil. The organic carbon contents of the soil with no compost and no mineral fertilizer amendment (i.e. the control) were similar to organic carbon content at the onset of the study. The highest values of SOC were obtained under compost + mineral fertilizer treatment followed by the compost treatment. The lowest value was obtained under mulching treatment in both years. Contrary to expectation, the control plots were high in SOC than in mulched plots. The SOC values recorded at both depths during the study were generally low.

Table 4.14: Effects of fertility management options on soil pH after two years cropping seasons

Fertility management options	pHwater	
	0 - 10 cm depth	10 - 20 cm depth
Control	5.83	5.58
Compost	6.34	5.74
NPK + Urea	5.64	5.38
Mulching	5.84	5.51
Compost + NPK + Urea	5.98	5.57
Fpr	0.001	0.01
Lsd (0.05)	0.20	0.20

Table 4.15: Effects of tillage practices on soil organic carbon content at 0 - 10 cm depth

Tillage Practices	SOC in 2012	SOC in 2013
	(%)	
Zero tillage	1.14	1.14
Ripping	1.09	1.08
Tied ridging	1.25	1.20
Conventional tillage	1.03	0.90
Fpr	0.60	0.50
Lsd	0.40	0.30

Table 4.16: Effects of fertility management options on soil organic carbon content

Fertility management options	SOC (%) in 2012		SOC (%) in 2013	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Control	1.10	0.77	1.09	0.72
Compost	1.21	0.93	1.22	0.93
NPK + Urea	1.11	0.74	1.04	0.74
Mulching	0.97	0.73	0.97	0.74
Compost + NPK + Urea	1.22	0.86	1.24	0.86
Fpr	0.06	0.22	0.05	0.24
Lsd	0.19	0.19	0.20	0.17

4.4.1.2. Discussion

Soil pH is the deciding factor for availability of plant nutrients (Rahman and Ranamukhaarachchi, 2003). It influences the occurrence and the activities of soil microorganisms and eventually affects both organic matter decomposition and nutrient availability. The highest soil pH observed under compost application could be attributed to self – liming (alkalinity) caused by the mineralization of organic matter and release of basic cations and production of OH^- by NH_4^+ during the decomposition and ammonification of compost. Haynes and Mokolobate (2001) reported that the process of ammonification increases soil pH as OH^- is produced by NH_4^+ that is mineralized from organic matter. According to Magdoff and Weil (2004), organic matter applied to the soil is effective in reducing Al saturation in subsoil horizons, a desirable effect not easily achieved by using agricultural limestone, which is relatively mobile in soils. Organic material forms Ca - complexes that move Ca down the profile with percolating water, thus ameliorating the acid subsoil layers (Hue and Licudine, 1999). This explains why the pH in the 0-20 cm layer under compost application was significantly higher than that under the mulched plots, NPK + Urea treated plots and the control. The insignificant difference observed in soil pH between compost + NPK + Urea treated plots and plots amended with sole compost was not surprising because the former also received compost treatment which exerted some degree of ameliorative effect on the soil similar to the sole compost treated plots. These results are also consistent with the work of Ikerra *et al.* (2006) who reported an increase in soil pH consecutive to compost application. Bekunda *et al*. (1997) reported from selected experimental results in Africa that continuous application of mineral fertilizer (especially N fertilizer) without organic input led to soil acidification and decline in soil organic matter.

The soil organic carbon content recorded was low. According to Metson (1961), a productive soil should have an organic carbon content of 2.3 %. According to Greenland (1994), low organic carbon can result in reduction in crop response to fertilizers. Sedogo (1981) previously observed that low organic matter content of sub - Saharan Africa's soils reduces crop response to fertilizer application. Even though it is recognized that soil organic carbon is not a sensitive parameter of a soil quality as it varied slowly (Ouattara, 1994), the results indicated an increase in soil organic carbon content under compost and compost + NPK + urea amendments over the control at a shallow depth (0 – 10 cm). This observation is in line with results of other studies showing the addition of exogenous organic matter like compost resulting in an enhancement of soil organic carbon storage in addition to improvement of many functions related to the presence of organic matter (Lashermes *et al*. 2009). In tropical soils, the impact of organic amendment on long - term carbon storage might be rather small (Mandal *et al*., 2007). However, many studies noted their beneficial effects on nutrient cycling (Ngo *et al*., 2012; Kaur *et al*., 2005). The organic carbon content of the control was similar to the soil organic carbon content at the onset of the study.

In this study, tillage practices did not affect the soil organic carbon content though the highest values were recorded under no - till practice. This may be due to the short - term nature of the experiment (2 years). Other studies have previously highlighted the improvement in soil organic carbon content under no tillage practice after several years (Ouattara, 1994; Mazzoncini *et al*. 2011; Dimassi *et al*. 2014; Villarino *et al*. 2014). According to Jenkinson (1990), most of SOM in agricultural soils is degradation resistant and turns over much more slowly. The labile fraction which plays a prominent role in soil nutrient dynamics and which may function as a temporal nutrient reservoir (Ouattara, 1994), declines with cultivation (Cambardella and Elliott, 1994), and when a fallow period is included in the rotation system (Biederbeck *et al.*, 1994).

4.4.2. Effects of tillage and fertility management options on soil available nitrogen content

4.4.2.1. Results

4.4.2.1.1. Soil ammonium - N as affected by tillage practices and fertility management options

The statistical analysis generally showed a significant difference in terms of tillage practices on soil ammonium - nitrogen content (Appendix 1). During the early period of the rainy season (August), the soil ammonium - N content was higher under tied ridging practice compared to the control, ripping and the conventional tillage, but there was no significant difference between the three latter tillage practices (Figure 4.3). During the peak rainfall period (September), the ammonium - N content decreased under tied ridging and conventional tillage practices while it increased under ripping and zero tillage practices (Figure 4.2). There was a general decline in NH_4^+ under all tillage practices after the last week in September to the first week in October. Zero tillage consistently maintained a relatively higher level of the nutrients throughout the study period except in the month of August. It is quite clear from the results that NH_4^+ levels under ripping and zero tillage were statistically at par throughout the entire study period. Interestingly, there was somewhat a parallel relationship between NH_4^+ under tied ridging and conventional tillage throughout August. Around the middle of September, the levels under both tillage systems were the same (converged) and then diverged from the last week of September to the end of the study.

The statistical analysis did not show any significant difference in soil N ammonium - N under the different fertility management options (Appendix 1). There was an increase in soil ammonium - N content under compost application from August to late September after which there was a decline (Figure 4.3). The compost treated plots noticeably produced higher NH_4^+ levels than all other plots after the second week in August to the last week in September. There was a general decline in the level of the nutrients in all plots (except compost treated plots) at the beginning of September. The NH_4^+- N level in all plots peaked around the beginning of the last week in September and thereafter showed a decline. The level of NH_4^+ under the amendments and the control were generally low (< 5.0 mg/kg soil) (Figure 4.3).

The results of the study showed that both the tillage practices and fertility management options affected soil nitrate - nitrogen content during the cropping season (Appendix 2). Soil nitrate - N content increased under tied ridging and conventional tillage practices during the peak rainfall period while it did not show much variation under zero tillage and ripping practices (Figure 4.4).

There was a continuous increase in soil nitrate - N under NPK and urea application throughout the cropping season compared to the other fertility management options where the nitrate - N content started decreasing in September (Figure 4.5). Nitrate – N was immobilised under mulching throughout the period since nitrate-N content under mulching practice was lower than that of the control plots.

The mixed model analysis showed that the tillage practices did not affect the soil total mineral N content (Appendix 3). However, there was an increase in soil total mineral N content from the beginning of the cropping season until late September when there was a decline under all the tillage practices (Figure 4.6). Soil mineral - N followed the same trend under the various fertility management options apart from urea + NPK treatment under which it increased throughout the measurement period (Figure 4.7).

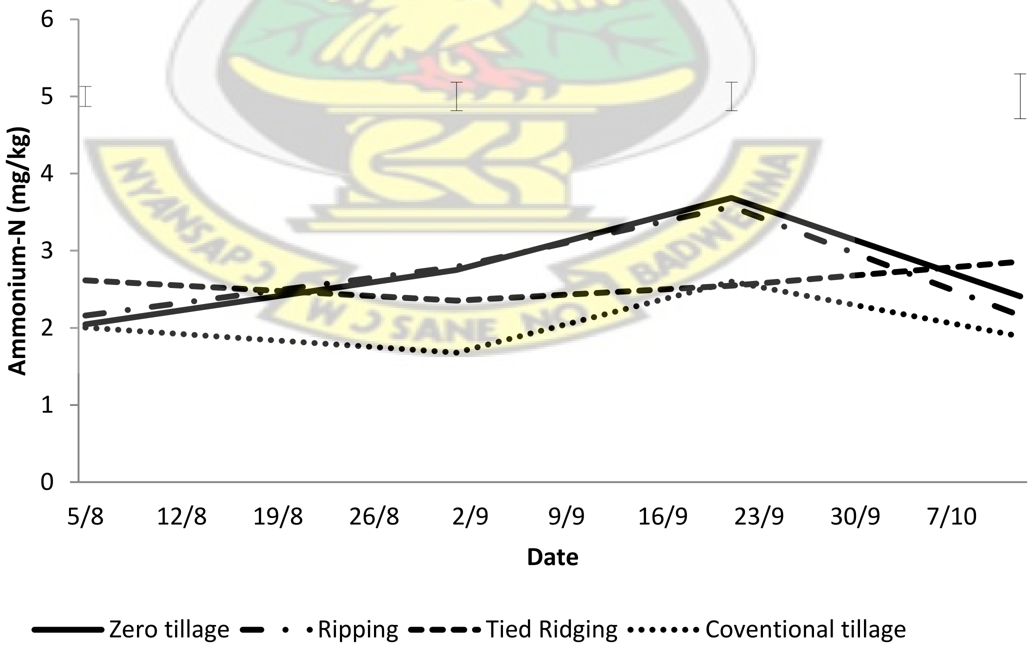

Figure 4.2: Tillage practices effects on soil ammonium - N content over time

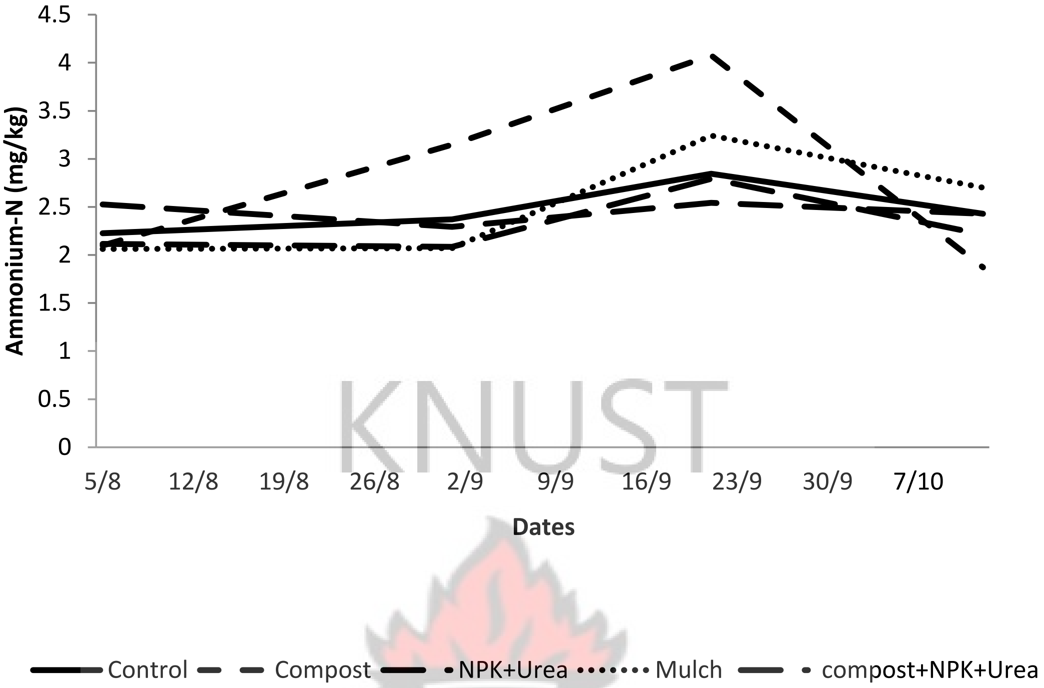

Figure 4.3 : Fertility management options effects on soil ammonium - N dynamics

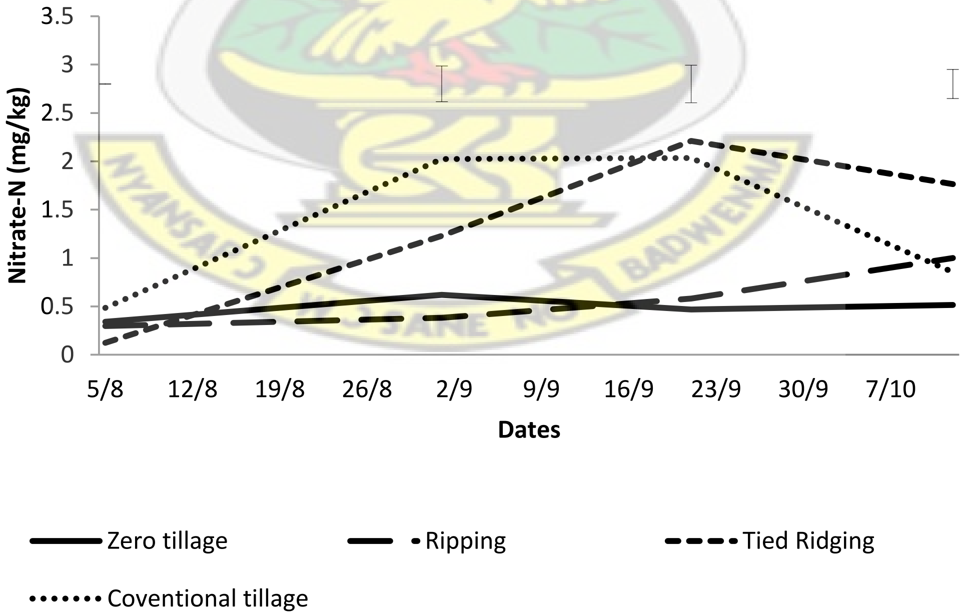

Figure 4.4: Tillage practices effects on soil nitrate - N content over time

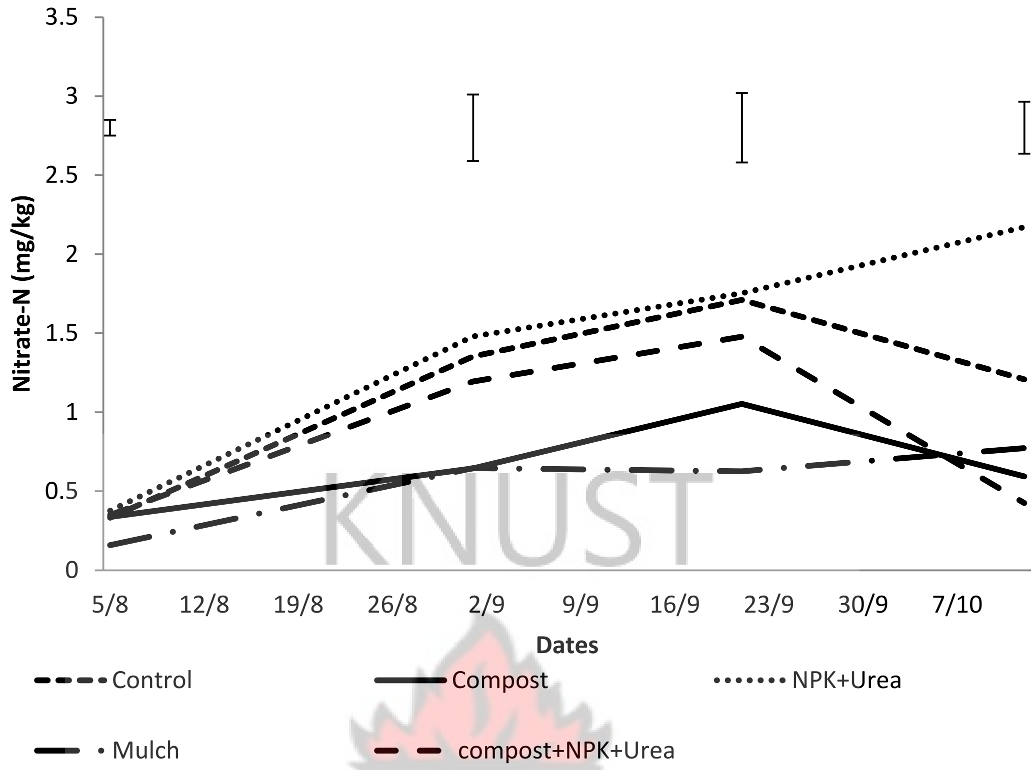

Figure 4.5 : Effects of soil fertility management options effects on soil nitrate - N content

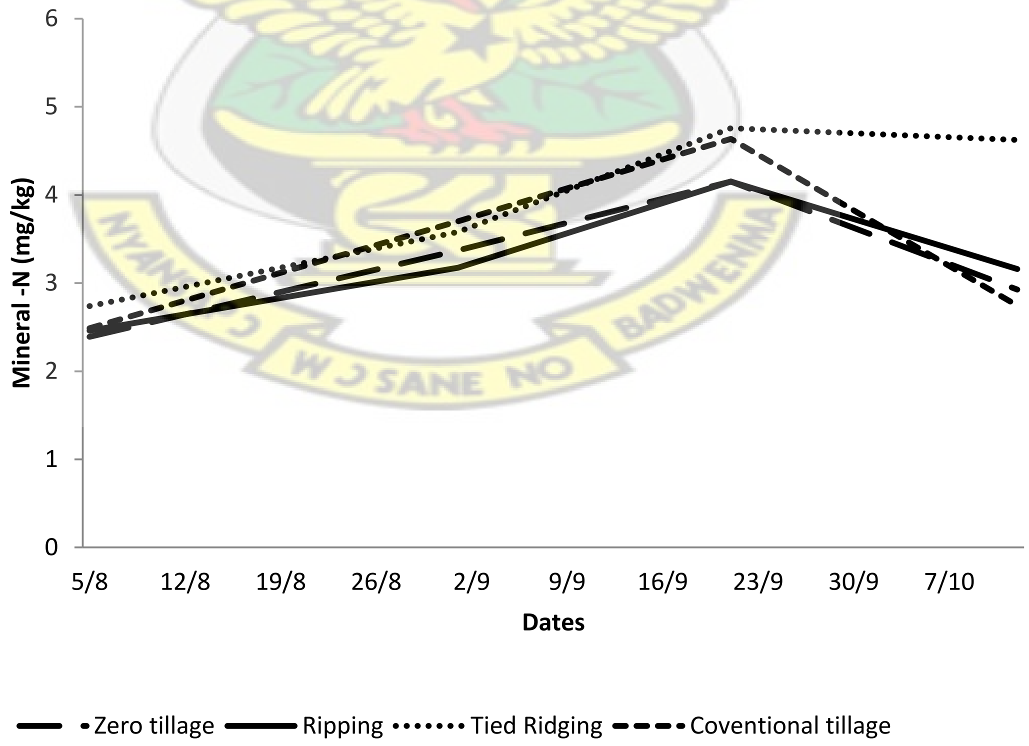

Figure 4.6: Soil total mineral - N dynamics under tillage practices

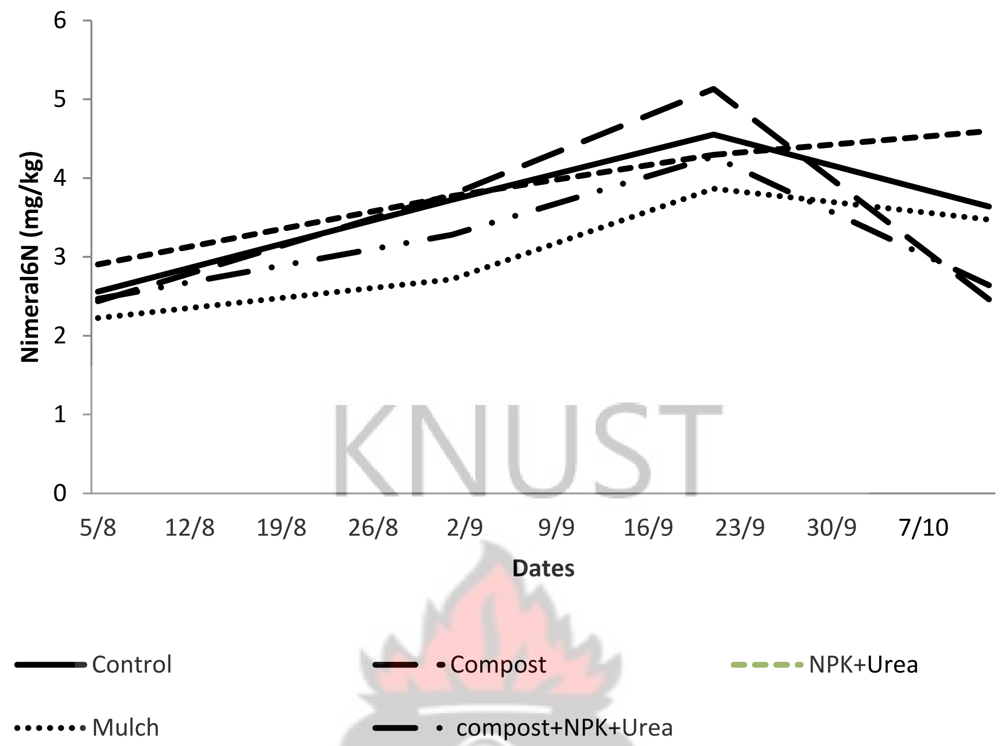

Figure 4.7: Fertility management options effects on soil mineral - N dynamics

4.4.2.2. Discussion

Though nitrate – N levels under the different tillage practices were generally low, the conventionally tilled plots produced significantly higher values from the beginning of the sampling period until late September. The high values recorded was due to the higher soil disturbance exposing organic matter to decomposition, this notwithstanding the lowest ammonium - N values observed under the conventional tillage. During the peak rainfall period (September), the ammonium - N content decreased under tied - ridging and conventional tillage practices while it increased under ripping and zero tillage practices (Figure 4.3). At the same time the nitrate - N content increased under tied - ridging and conventional tillage and decreased under zero tillage and ripping practices (Figure 4.5). This observation has implication for nitrogen loss from the soil system since N stored in the form of nitrate is subject to more leaching losses than N in the form of ammonia. This suggests that conventional tillage and tied - ridging which impose a higher degree of soil disturbance on croplands than the ripping and the zero tillage practices may result in more storage of N in the form of nitrate and less storage in the form of ammonium in the rainy season. According to Tsai *et al.* (1992), N maintained as NH_4^+ in the soil should be available for late - season uptake.

Nitrification is the microbial oxidation of ammonia to nitrite and further to nitrate.

The nitrification process is in two steps:

1. Ammonia → Nitrite = $NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$
2. Nitrite → Nitrate = $NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$

This is a key set of reactions in relation to N losses since they transform the relatively immobile ammonium ion into nitrate, which can be leached or denitrified. The transformation of nitrite to nitrate happens in the presence of water. Since there was an increase in water content under tied ridging and conventional tillage during the peak rainfall period, it was expected to produce an increase in nitrate levels under these tillage practices at the same period. The N losses through leaching and denitrification could also be greater under moist condition (tied ridging and conventional tillage). The results are in line with the findings of Constantin *et al*. (2011), Jin *et al*. (2013) and Castellano *et al*. (2014) who reported high N loss under tillage practices that disturb the soil structure and retain more moisture.

4.4.3. Soil total nitrogen, phosphorus and potassium content as affected by fertility management options

4.4.3.1. Results

Soil total N content ranged from 0.018% to 0.066 % and decreased with year and with depth (Table 4.17). Soil total N was greater in 2012 than in 2013 under all the treatments. The 0 - 10 cm depth was richer in N compared to 10 - 20 cm depth. With regard to soil fertility management options, the highest total N content was observed under compost + NPK + urea treatment. The total nitrogen content showed positive linear correlation with organic carbon content with R^2 of 0.55 (Figure 4.8).

Table 4.18 shows the effects of fertility management options on soil total P content. In 2012, soil total P varied from 94 mg kg^{-1} soil in control plots to 102 mg kg^{-1} soil in compost + NPK + urea plots at 0 – 10 cm depth. Compared to 0 – 10 cm depth, higher levels of total P was recorded in the 10 – 20 cm depth which ranged from 145 mg kg^{-1} soil to 165 mg kg^{-1} soil. During the first year of the experiment, the fertility management options did not affect ($p < 0.05$) soil total P content at both 0 - 10 cm and 10 - 20 cm depths. In 2013, total P content ranged from 121 – 151 mg/kg soil and 120 – 140 mg kg^{-1} soil respectively at 0 – 10 cm and 10 – 20 cm depths. It was observed that total P content increased in the top soil (0 – 10 cm) from 2012 to 2013. It however, showed a decline in the subsoil (10 – 20 cm) from the first year to the second year. During the second year of the experiment, the fertility management options influenced significantly soil total P content at 10 - 20 cm depth but not at 0 – 10 cm depth. The compost, the compost + NPK + Urea and NPK + Urea treatments increased the soil total P content compared to the control and the mulching treatment.

Total K values ranged from 160 mg kg^{-1} soil to 400 mg/kg soil over the two years of experimentation. The results showed a decreasing trend of soil K at both depths under the fertility management options (Table 4.19). For example, total K in compost treated plots showed about 46% decline in the topsoil and 52% in the subsoil. Similarly, K content under integrated application of compost + NPK + urea showed about 37% and 58% decline in the topsoil and the subsoil respectively. In both cases, decline in the K content was more pronounced in the subsoil than in the topsoil. However, at each soil depth, the differences in total K under the amendments and the control were statistically similar ($P > 0.05$) in both years.

Table 4.17: Effect of fertility management options on soil total nitrogen content

Fertility management options	Total N (%) in 2012		Total N (%) in 2013	
	0 - 10 cm	10 - 20 cm	0 - 10 cm	10 - 20 cm
Control	0.058	0.035	0.030	0.021
Compost	0.062	0.037	0.034	0.020
NPK + urea	0.053	0.031	0.031	0.019
Mulching	0.048	0.036	0.026	0.018
Compost + NPK + urea	0.066	0.028	0.033	0.022
Fpr	0.028	0.040	0.050	0.050
Lsd	0.011	0.007	0.005	0.004

Table 4.18: Effects of fertility management options on soil total P

Fertility management options	Total P (mg kg^{-1} soil) 2012		Total P (mg kg^{-1} soil) 2013	
	0 - 10 cm	10 - 20 cm	0 - 10 cm	10 - 20 cm
Control	94	165	121	132
Compost	103	161	131	140
NPK + Urea	96	156	125	138
Mulch	97	149	126	120
Compost + NPK + Urea	102	145	151	139
Fpr	0.91	0.30	0.50	0.04
Lsd (0.05)	24	21	38	14

Table 4.19: Effects of fertility management options on soil total K

Fertility management options	Total K (mg/kg soil) (2012)		Total K (mg/kg soil) (2013)	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Control	287	347	195	176
Compost	342	359	185	174
NPK + Urea	298	309	178	167
Mulching	286	368	170	160
Compost + NPK + Urea	311	400	197	169
Fpr	0.50	0.30	0.17	0.60
Lsd (0.05)	76.8	214	25	24

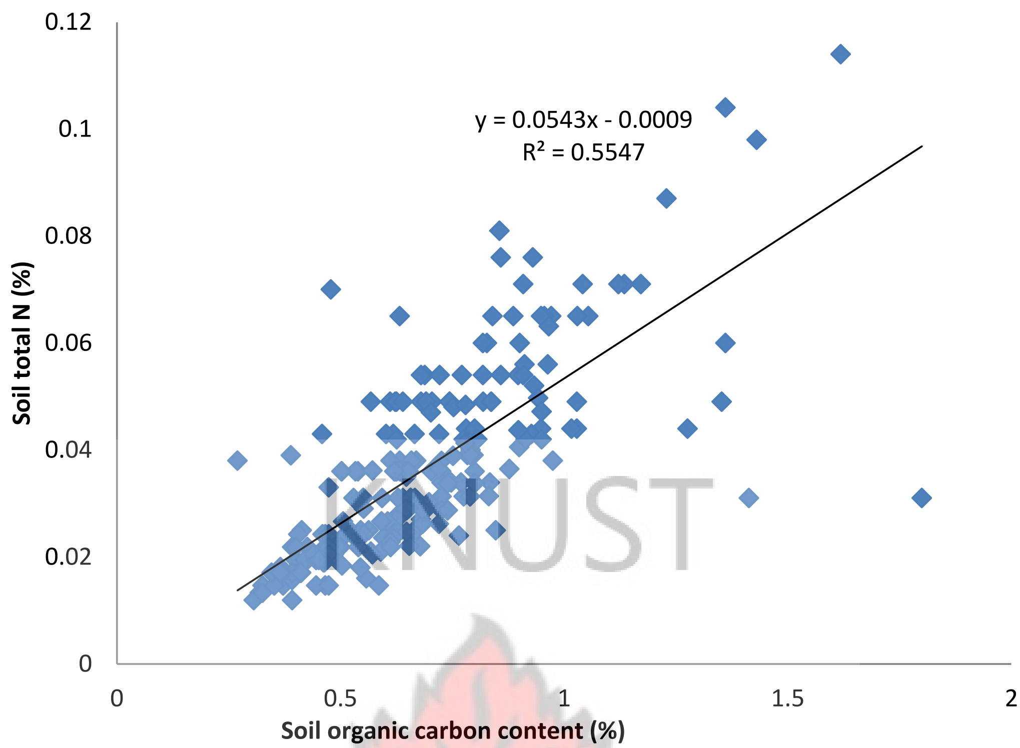

Figure 4.8 : Relationship between soil total N and organic carbon content

4.4.3.2. Discussion

Soil total nitrogen levels of 0.026 to 0.066 % under the tillage practices and fertility management options were very low. This was particularly due to the low soil organic carbon levels (0.97 – 1.22%) found in this study following tillage practices and amendment and was in line with the findings of Kiba (2012) who reported low levels under cropping system in Burkina Faso. This observation could also be partially attributed to N losses by mainly leaching, surface runoff, denitrification, etc. The highest N level observed under compost and compost + NPK + Urea plots were due to the organic matter content improvement under these treatments. According to Kemmitt *et al.* (2008), the soil organic matter is composed of 5 - 6 % nitrogen. The NPK amendment imposed on the compost + NPK + Urea plots, which was later followed by a 'top dress' with urea is also attributable to the highest N levels recorded in these plots. The nitrogen content of the fertilizers made a significant contribution to the total N initially in the soil (Table 4.1). Similar results were obtained by Logah (2009) who observed higher N contents in plots treated with poultry manure and nitrogenous fertilizer than non - amended plots under maize based cropping systems in Ghana. The low nitrogen level observed under mulching practice could be due to the immobilization of nitrogen by microorganisms for their activity of mulch material break down and decomposition. Several studies have shown that materials with high C/N led to the immobilization of soil N by the microorganisms (Tu *et al*., 2006 and Zhang, 2006).

During the first year of the experiment, the fertility management options did not affect soil total P content at both 0 - 10 cm and 10 - 20 cm depths. This could be due to the inherent low P content of the soil of the research site (Table 4.1. The low P content of soils in Burkina Faso has been previously reported by Sédogo (1981) and Kiba (2012). The nutrient from the different fertility management option might have been used by the sorghum for dry matter production since good response of sorghum to phosphorus application in soils in Burkina Faso have been documented (Bonzi *et al*., 2011). During the second year of the experiment, the fertility management options affected significantly soil total P content at 10 - 20 cm depth. The compost, the compost + NPK + urea and NPK + urea treatments increased the soil total P content compared to the control and the mulching treatment due to the supply and accumulation of P from the compost and NPK applied over time. Since phosphorus is not mobile, it is less subject to leaching and the excess is stored into the soil for the subsequent cropping season (Liu *et al*., 2012)

The fertility management options did not significantly affect soil total K content during the two years of experimentation. This could be explained by the high uptake of K especially by biomass (Table 4.21). Therefore, when the sorghum biomass is not returned to the soil it can lead to a loss of high amount of K from the cropping system. Also, since K is mobile in the soil, the application of high amount of mineral K can easily leach out of the soil profile. Mulching did not increase soil K content despite the high K content of the sorghum straw (Table 4.2) because the straw had to undergo a decomposition process before K is released to the soil - plant system. These results are consistent with those obtained by Freschet *et al*. (2013) and Sharif *et al*. (2014) who observed an increase in soil K content after the third year of crop residues application.

4.5. Tillage practices and fertility management options effects on sorghum NPK uptake and utilization efficiency

4.5.1. Effect of tillage and fertility management on NPK uptake

4.5.1.1. Results

Tables 4.20 - 4.22 show the effects of tillage practices on sorghum NPK uptake. Tillage practices affected ($p < 0.05$) only the sorghum grain P uptake. Phosphorus uptake was higher under conventional tillage and tied ridging practices compared to the zero tillage and the ripping practices. Specifically, P uptake in conventionally tilled plots was about 35 % higher than uptake in the no - till plots.

For the biomass nutrient uptake, both N and P uptake were significantly affected by tillage options (Figure 4.21). Conventional tillage and ripping practices increased sorghum biomass N and P uptake over the zero tillage. Biomass K uptake was not significantly affected by tillage practices. As far as the total nutrient uptake (grain uptake + biomass uptake) under tillage practices is concerned, only P total uptake was significantly influenced (Table 4.22). Conventional tillage produced the highest total P uptake while the least was observed under ridging and zero tillage.

The effect of fertility management options on N, P and K uptake by sorghum is presented in Tables 4.23 to 4.25. Fertility management options greatly affected sorghum grain N, P and K uptake (Table 4.23). Sorghum grain uptake of N, P and K was higher under compost + NPK + urea treatment followed by NPK + urea treatment. The lowest nutrient uptake values were observed under mulching practice. Biomass total N, P and K uptake by sorghum also followed the same pattern as the grain N, P and K uptake (Table 4.24). The total N, P and K uptakes were similarly affected by fertility management options in a decreasing trend of compost + NPK + urea > NPK + urea > compost > control > mulching.

Table 4.20: Tillage practices effects on sorghum grain N, P and K uptake (kg ha^{-1})

Tillage practices	N uptake	P uptake	K uptake
Zero tillage	32.48	4.72	9 .24
Ripping	27.39	4.97	9.22
Tied ridging	36.53	5.11	11.53
Conventional tillage	37.94	7.22	12.08
Fpr	0.22	0.03	0.2
Lsd (0.05)	10.9	1.8	3.4

Table 4.21: Tillage practices effects on sorghum biomass N, P and K uptake (kg ha^{-1})

Tillage practices	N uptake	P uptake	K uptake
Zero tillage	27.08	1.93	61.72
Ripping	31.24	2.16	62.15
Tied ridging	22.18	1.51	75.25
Conventional tillage	36.68	2.88	70.98
Fpr	0.03	0.002	0.56
Lsd	9.7	0.6	23

Table 4.22: Tillage practices effects on sorghum total N, P and K uptake (kg ha^{-1})

Tillage practices	N uptake	P uptake	K uptake
Zero tillage	59.6	6.6	71
Ripping	58.6	7.1	71.4
Tied ridging	58.7	6.6	86.8
Conventional tillage	74.6	10.1	83.1
Fpr	0.31	0.017	0.5
Lsd	20	2.4	26

Table 4.23: Fertility management options effects on sorghum grain N, P and K uptake (kg ha^{-1})

Fertility management options	N uptake	P uptake	K uptake
Control	18.99	3.97	6.87
Compost	32.71	6.19	11.04
NPK + urea	42.77	6.29	12.27
Mulch	16.92	3.09	5.22
Compost + NPK + urea	56.54	7.99	17.18
Fpr	0.001	0.001	0.001
Lsd (p <0.05)	12	2	3.9

Table 4.24: Fertility management options effects on sorghum biomass N, P and K uptake (kg ha^{-1})

Fertility management options	N uptake	P uptake	K uptake
Control	23.57	1.70	44.68
Compost	27.38	2.05	65.83
NPK + urea	36.61	2.38	76.41
Mulch	17.72	1.41	39.51
Compost + NPK + urea	41.20	3.07	111.20
Fpr	0.001	0.001	0.001
Lsd (p <0.05)	10.9	0.7	25

Table 4.25: Fertility management options effects on sorghum total N, P and K uptake (kg kg^{-1})

Fertility management options	N uptake	P uptake	K uptake
Control	42.60	0.57	51.50
Compost	60.10	0.82	76.90
NPK + Urea	79.40	0.88	88.70
Mulch	34.60	0.45	44.70
Compost + NPK + Urea	97.70	1.10	128.40
Fpr	0.001	0.001	0.001
Lsd (p <0.05)	22	0.27	29

4.5.1.2. Discussion

Nitrogen uptake by sorghum grain and fodder was significantly higher under compost + NPK +urea and NPK + urea than the compost, mulching and the control due to better root growth, absorption by roots and increase in dry matter production in the former. Taalab *et al*. (2008) found that nitrogen uptake by sorghum under compost + NPK treatment was higher with application of 60 kg N ha^{-1} than no nitrogen. In their study, Sharif *et al*. (2014) observed higher N uptake by sorghum with incorporation of compost over fertilizer application. Ballaki and Badanur (2012) also reported increase in nitrogen uptake by sorghum with addition of organic fertilizer over the control.

Phosphorus uptake was higher under conventional tillage and tied ridging practices compared to the zero tillage and the ripping. This observation could be due to the improvement in soil water content under these practices (Table 4.10). Findings have demonstrated a positive interaction between soil moisture and P uptake because improved soil moisture status increases soil P availability (Ouattara, 1994). The highest P uptakes in grain and biomass were observed under compost + NPK + urea followed by the NPK + urea treatment which were significantly different from the control. This may be attributed to increased absorption of P by plants due to better root growth with additional nitrogen supply through compost.

Potassium uptake by sorghum was higher under compost + NPK + urea, NPK + urea and compost treatments than the control. This may be attributed to contribution of potassium from the compost (Table 4.2) and NPK fertilizer to these plots compared to the control which received no amendment. The sorghum straw also contained high level of K but must undergo a decomposition process before being made available to the crop. Erdal *et al.* (2000) reported that nutrient accumulation in plant were enhanced by the use of organic materials mixed with chemical fertilizers. The lowest nutrient uptake in the control plots showed the extent of land degradation (nutrient depletion) at the research site.

4.5.2. Nutrient utilization efficiency under different tillage practices and fertility management options

4.5.2.1. Results

The tillage practices affected nitrogen and phosphorus utilization efficiencies significantly (Table 4.26). The tillage practices did not have any significant effect on potassium utilization efficiency. However, K utilization efficiency under zero tillage and ripping practices showed 12 % and11 % increases over that of tied - ridging and conventional tillage, respectively.

Nitrogen utilization efficiency values ranged from 66.43 kg kg^{-1} under ripping to 57.58 kg kg^{-1} under conventional tillage practice. The nitrogen utilization efficiency under the tillage practices was in the decreasing order of Ripping > Tied ridging > Zero tillage > Conventional tillage.

Phosphorus utilization efficiency varied between 299 kg kg^{-1} under conventional tillage and 432 kg kg^{-1} under zero tillage (Table 4.26). Phosphorus utilization efficiency under the various tillage practices increased in the order of conventional tillage < tied ridging < ripping < zero tillage. Both nutrients (N and P) were more efficiently utilized under zero tillage than all other tillage practices.

The fertility management options influenced N and K utilization efficiency significantly (Table 4.27). Nitrogen utilization efficiency values under the fertility management options ranged from 57 kg kg^{-1} under compost + NPK + Urea to 68.6 kg kg^{-1} under the control.

Unlike N utilization efficiency, P and K utilization efficiencies were not influenced ($P>0.05$) by the various soil amendments during the study.

The tillage practices and fertility management options interacted significantly to affect N, P and K utilization efficiencies (Tables 4.28 – 4.30). The highest N utilization efficiency values were obtained under ripping x control and zero tillage x control interaction respectively with the NUE values of 77.88 and 71.89 kg kg^{-1} (Table 4.28). On the other hand, the highest P utilization efficiency value of 551 kg kg^{-1} was obtained under ripping x compost + NPK + Urea and ripping x mulching interactions (Table 4.29). The interactions of ripping with NPK + urea and with mulching treatments resulted in the highest KUE (Table 4.30).

Table 4.26: Tillage practices effects on NPK utilization efficiency (kg kg^{-1})

Tillage practices	NUE	PUE	KUE
Zero tillage	61.38	432	207.1
Ripping	66.43	401	203.5
Tied ridging	62.73	376	185.1
Conventional tillage	57.58	299	185.8
Fpr	0.04	0.03	0.1
Lsd	6	110	27

Table 4.27: Fertility management options effects on N, P and K utilization efficiency (kg kg^{-1})

Fertility management options	NUE	PUE	KUE
Control	68.60	320	185.3
Compost	61.59	332	183.0
NPK + Urea	60.97	419	214.8
Mulch	62.01	371	203.5
Compost + NPK + Urea	57.00	422	190.4
Fpr	0.03	0.09	0.3
Lsd	6	130	36

Table 4.28: Combined effects of Tillage practice and fertility management options on nutrient N utilization efficiency (kg kg^{-1})

	Control	Compost	NPK + urea	Mulch	Compost + NPK + urea
Zero tillage	62.31	66.76	58.41	64.45	54.98
Ripping	71.89	62.31	66.76	66.76	64.45
Tied ridging	77.88	62.31	58.41	58.41	56.64
Conventional tillage	62.31	54.98	60.30	58.41	51.92
Fpr	0.03				
Lsd (0.05)	6				

Table 4.29:Combined effect of tillage practices and fertility management options on nutrient P utilization efficiency (kg kg^{-1})

	Control	Compost	NPK + urea	Mulch	Compost + NPK + urea
Zero tillage	374	327	523	551	388
Ripping	291	261	402	374	551
Tied ridging	321	402	523	275	476
Conventional tillage	291	337	308	283	283
Fpr	0.04				
Lsd	124				

Table 4.30: Combined effect of tillage practice and fertility management options combined effects on nutrient K utilization efficiency (kg kg^{-1})

	Control	Compost	NPK + urea	Mulch	Compost + NPK + urea
Zero tillage	193	193	221	206	221
Ripping	171	162	238	238	206
Tied ridging	182	193	193	162	193
Conventional tillage	193	182	206	206	140
Fpr	0.036				
Lsd	40				

4.5.2.2. Discussion

The dry matter produced with a unit of N and P absorbed was higher in ripping and zero tillage compared to that of the conventional. This was possibly due to the fact that the disturbance of the soil under conventional tillage improved N and P availability and uptake by the sorghum grain (Table 4.20). Similarly, Yadav *et al.* (2013) reported a high N and P concentration in sorghum grain under conventional tillage over no-tillage practice.

The highest N utilization efficiency was obtained under control treatment whilst the lowest one was observed in compost + NPK + urea treated plots. A possible reason is that the rate of nutrient applied in the compost + NPK + compost was higher than required and the excess was not translated to additional grain production. Fatondji (2002) observed in millet cropping system in Niger an increase in nutrient uptake and decrease in nutrient utilization efficiency under combined application of compost and NPK.

Compost + NPK + urea application interacted with ripping to improve P utilization efficiency. The interactions of ripping with NPK + urea also improved K utilization efficiency. Studies have shown that minimum tillage practices combined with organic and mineral fertilizers have the potential to moderate nutrient uptake and improve their utilization efficiencies (Baligar *et al.,* 2001, Ishaq *et al.,* 2001 and Fatondji, 2002)

4.6. Impact of tillage, soil amendment and their interaction on sorghum growth and yield

4.6.1. Tillage and soil amendment effects on the growth of sorghum

4.6.1.1. Results

The height of sorghum was used as an indicator of growth assessment. The repeated mixed models analysis results showed the effect of both time, tillage practices and fertility management options on the growth of sorghum during 2012 and 2013 cropping seasons (Tables 4.31 and 4.32).

During the 2012 cropping season, sorghum growth was only a function of time and fertility management options. Tillage practices did not affect sorghum height during 2012 cropping season (Table 4.31). The following trend was observed with regard to height under the different fertility management options: Compost + NPK + urea > NPK > Compost > Control >Mulching.

During 2013 cropping season, time, tillage practices and fertility management options significantly affected sorghum growth (Table 4.32). The effects of fertility management options on sorghum height followed the same trend as during 2012 cropping season. The combination of compost and mineral fertiliser produced the tallest plants while the shortest plants were obtained under mulching practice during both years of experimentation. With regard to tillage practices, the highest values were recorded under tied ridging practice followed successively by conventional tillage, ripping and zero tillage practices.

Table 4.31: Mixed model analysis of sorghun growth in 2012

Fixed term	Wald statistic	d.f.	Chi pr
Time	10537.12	2	<0.001
Tillage practice	2.76	3	0.430
Fertility managenent	75.48	4	<0.001
Time x tillage practice	19.85	6	0.003
Time x fertility managenent	104.48	8	<0.001
Tillage practice x fertility management	5.93	12	0.920
Time x tillage practice x fertility management	17.74	24	0.816
Fertility management options	Height (cm)		
	30 DAS	60 DAS	90 DAS
Control	16.79	73.42	146.92
Compost	19.83	85.96	167.17
NPK+Urea	23.29	98.17	184.00
Mulching	16.33	70.83	146.92
Compost + NPK + Urea	24.79	101.83	189.08
Sed	4.8		

DAS=Days After Sowing

Table 4.32: Mixed model analysis of sorghun growth in 2013

Fixed term	Wald statistic	d.f.	chi pr
Time	4876.05	2	<0.001
Tillage practice	11.71	3	0.008
Tertility management	30.72	4	<0.001
Time x tillage practice	18.25	6	0.006
Time x fertility managenent	42.50	8	<0.001
Tillage practice x fertility management	2.78	12	0.997
Time x tillage practice x fertility management	7.09	24	1.000

Fertility management options	Height (cm)		
	30DAS	60DAS	90DAS
Control	17.67	79.00	149.25
Compost	18.75	96.08	164.17
NPK+Urea	21.96	108.83	173.83
Mulching	16.67	81.08	151.50
Compost + NPK + Urea	23.83	116.92	185.17
Sed	7		

Tillage practices	Height (cm)		
	30 DAS	60 DAS	90 DAS
Zero tillage	17.70	85.73	154.53
Ripping	19.53	89.67	157.40
Tied ridging	23.37	106.07	174.60
Conventional tillage	18.50	104.07	172.60
Sed	6.2		

Sed = Standard error of the difference of means; DAS = days after sowing

4.6.1.2. Discussion

The differences in the height of sorghum as affected by tillage practices during the second year could be due to the favourable effects of tillage on soil porosity and soil water content that led to better root development and improved nutrient and water uptake by the plants. The results showed improved water storage under tied ridging practices compared to zero tillage and ripping (Table 4.7) and so explained why taller plants were observed under the tied ridging. The results corroborates with those obtained by Pieri *et al.* (1992) in Burkina Faso, Kouyaté *et al.* (2000) in Mali and Mesfin *et al.* (2010) in Ethiopia who observed higher sorghum growth rate under tied ridging and conventional tillage practices than zero tillage and ripping.

The lowest plant height observed under mulching practice in both years of the experiment could be due to the immobilization of nitrogen by the micro-organisms for straw material breakdown activities. The total nitrogen content under mulching practice was very low after the first year of the experiment (Table 4.17). Nitrogen immobilization under mulching without mineral fertilizer application has been previously reported by Mafongoya *et al.* (2006) in cotton based copping system. Zida (2011) observed a decrease in soil total N consecutive to mulching.

The combination of compost and mineral fertilizer gave the best result in terms of sorghum growth because of the amount of nutrients made available to the soil- crop system during the growing stage. The NPK and urea made nutrients directly available to the crop while the compost released the nutrient slowly during the cropping period. The beneficial effects of combined compost and mineral fertilizers on sorghum growth have previously been highlighted by Ouedraogo *et al*. (2004), Odlare *et al*. (2013) and Patel *et al*. (2013).

4.6.2. Impact of tillage and amendment and their interaction on sorghum yield

4.6.2.1. Results

4.6.2.1.1. Effects of tillage and fertility management options on sorghum yield

The mixed model analysis did not show any significant difference between the tillage practices at chi probability level of 5% (Tables 4.33 - 4.36). In 2012, ripping increased sorghum grain yield by 14% while the conventional tillage and the tied ridging decreased it by 29% and 40% compared to the no - till practice (Table 4.33). In 2013, the tillage options led to decrease in sorghum grain yield by 13%, 5% and 1% respectively under ripping, tied ridging and the conventional tillage (Table 4.34).

The mixed models analysis at chi probability level of 5% showed significant differences between fertility management options with respect to sorghum yields (Tables 4.33 - 4.36). In 2012, Compost + NPK + urea, NPK + urea and compost application increased grain yield respectively by 102%, 69% and 36% (Table 4.33). In 2013, application of compost + NPK + urea, NPK + urea and compost led to 74%, 50% and 29% increase respectively in grain yield. In the same year, grain yield decrease of 30 % was observed under mulching compared to the control (Table 4.34). Mulching did not influence grain yield ($p < 0.05$) in 2013. Sorghum biomass yield followed the same trend as the grain yield under the various fertility management options in 2012 and 2013 (Tables 4.35 and 4.36).

4.6.2.1.2. Sorghum grain yield as affected by the interaction between tillage practices and soil fertility management options

During the first year of the experiment, the interaction of tillage practices and fertility management options did not impact significantly on sorghum grain and biomass yields (Tables 4.33 and 4.35). In 2013 however, the interaction between tillage practices and fertility management options significantly influenced both grain and biomass yields (Figures 4.9 and 4.10). The two - year cumulative effect of zero tillage x compost + NPK + urea increased sorghum grain yield by 28% compared to the conventional tillage with the same fertility management options (Figure 4.10).

Table 4.33: Mixed model analysis of sorghun grain yield in 2012

Random term	Component	s.e.	% Variance
Rep.Tillage practice	275976	198629	45
Residual	334205	83551	55
Total	610181		
Fixed term	**Wald statistic**	**d.f.**	**chi pr**
Tillage practice	0,74	3	0.863
Fertility management	29,58	4	<0.001
Tillage practice x fertility management	12,64	12	0.396

Fertility management	Grain Yield (kg/ha)	Increase (%)	Tillage practices	Grain Yield(kg/ha)	Increase (%)
Control	862		Zero tillage	966	
Compost	1176	36	Ripping	1105	14
NPK+Urea	1454	69	Tied ridging	1353	40
Mulching	602	-30	Conventional tillage	1243	29
Compost + NPK + Urea	1740	102			
Sed	236		Sed	478	

Sed = Standard error of the difference of means

Table 4.34: Mixed model analysis for sorghum grain yield in 2013

Random term	Component	s.e.	% Variance
Rep	136760	171510	29
Rep x tillage practice	81736	79353	18
Residual	246515	62415	53
Total	465011		
Fixed term	**Wald statistic**	**d.f.**	**chi pr**
Fillage practice	2.33	3	0.507
Fertility management	156.97	4	<0.001
Tillage practice x fertility management	32.02	12	0.001
Grain yield 2012	47.48	1	<0.001

Fertility management	Grain Yield(kg/ha)	Increase (%)	Tillage practices	Grain Yield(kg/ha)	Increase (%)
Control	1545		Zero tillage	2116	
Compost	1989	29	Ripping	1850	-13
NPK+Urea	2320	50	Tied ridging	2014	-5
Mulching	1543	0	Conventional tillage	2087	-1
Compost + NPK + Urea	2687	74			
Sed	250		Sed	299	

Sed = Standard error of the difference of means

Table 4.35: Mixed model analysis for sorghum biomass yield in 2012

Random term	Component	s.e.	% Variance
Residual	7145900	1597872	100
Total	7145900		
Fixed term	**Wald statistic**	**d.f.**	**chi pr**
Tillage practice	0.93	3	0.818
Fertility management	15.48	4	0.004
Tillage practice x Fertility management	7.54	12	0.82

Fertility management	Grain Yield(kg/ha)	Increase (%)	Tillage practices	Grain Yield(kg/ha)	Increase (%)
Control	3704		Zero tillage	4664	
Compost	4772	29	Ripping	4649	-0.3
NPK + Urea	6536	76	Tied ridging	5470	17
Mulching	3185	-14	Conventional tillage	4868	4
Compost + NPK + Urea	6368	72			
Sed	1091		Sed	976	

Sed = Standard error of the difference of means

Table 4.36: Mixed model analysis for sorghum biomass yield in 2013

Random term	Component		s.e.	% Variance	
Rep	123429		248573	8	
Rep x tillage practice	218623		293075	14	
Residual	1194900		305107	78	
Total	1536952				
Fixed term	**Wald statistic**		**d.f.**	**chi pr**	
Tillage practice	1.97		3	0.578	
Fertility management	80.52		4	<0.001	
Tillage practice x fertility management	20.65		12	0.056	
Biomass yield 2012	75.33		1	<0.001	
Fertility management	**Biomass Yield(kg/ha)**	**Increase (%)**	**Tillage practices**	**Biomass Yield(kg/ha)**	**Increase (%)**
Control	3810		Zero tillage	4015	
Compost	4593	21	Ripping	4612	15
NPK+Urea	4187	10	Tied ridging	3981	-1
Mulching	3793	0	Conventional tillage	4619	15
Compost + NPK + Urea	5152	35			
Sed	507		Sed	555	

Sed = Standard error of the difference of means

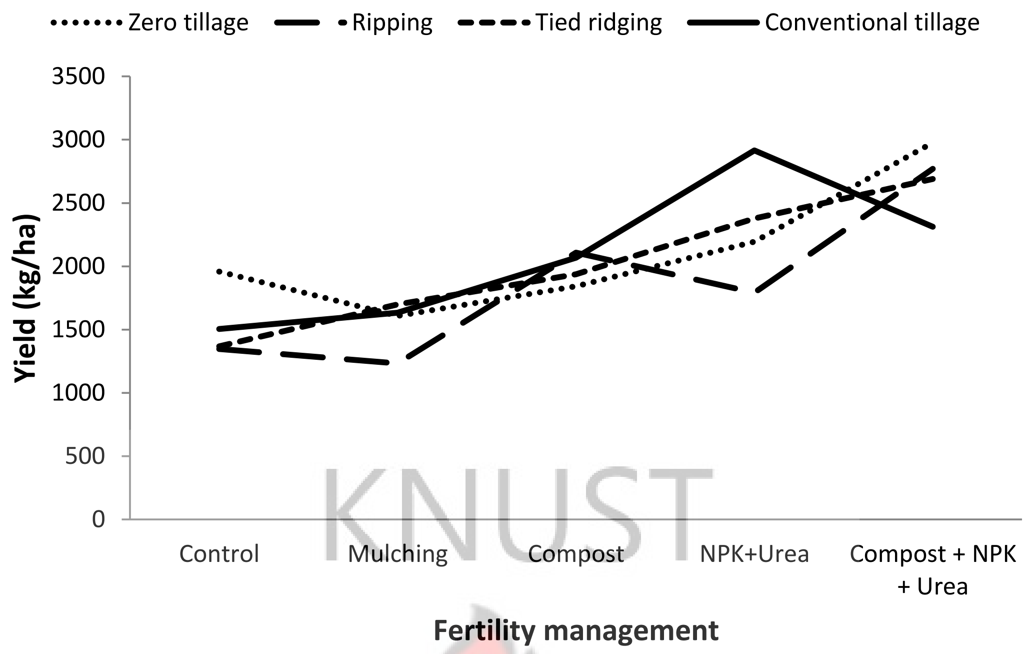

Figure 4.9 **:** Interaction between tillage practices and fertility management options on sorghum grain yield in 2013

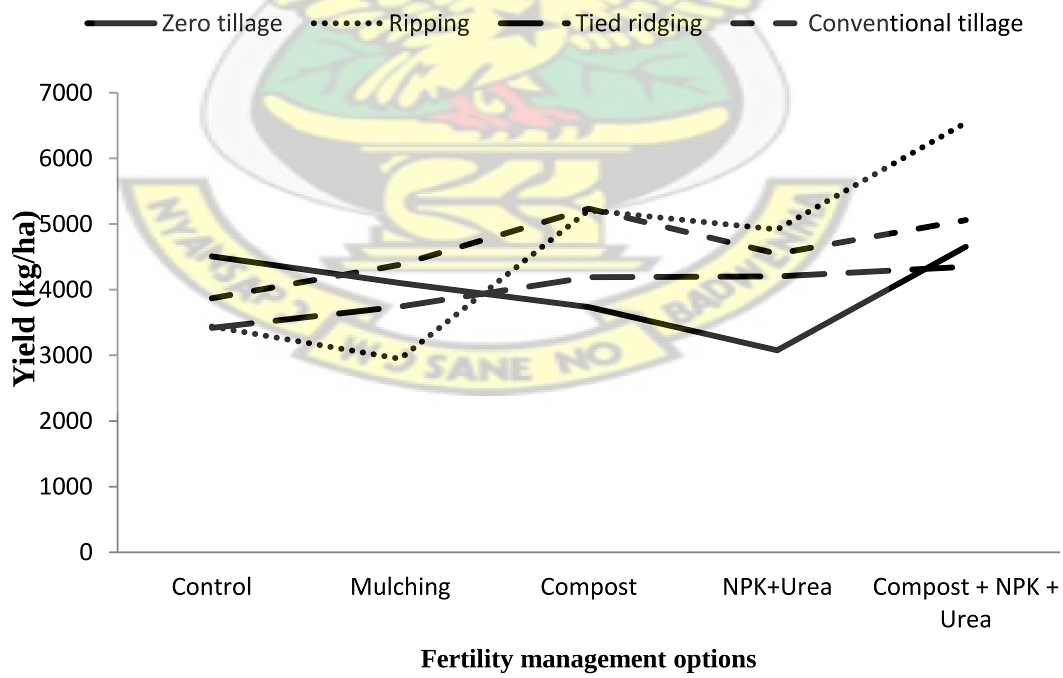

Figure 4.10: Interaction between tillage practices and fertility management options on sorghum biomass yield in 2013

4.6.2.2. Discussion

Zero tillage and reduced tillage systems have been reported to perform better (Mrabet, 2002), similarly and sometimes poorer than conventional tillage systems in terms of yields (Ouattara, 2007).

In this study, the fact that the statistical analysis did not show any significant difference between the tillage practices may be due to the high variability in the data because the tillage practices were located in the main plots. Rainfall was not a limiting factor during the two years. There was 40% increase in sorghum grain yield under tied ridging practice during the first year of the experiment and 5% decrease in the second year. The positive impact of zero tillage on sorghum grain yield during the second year of the experiment can be explained by the cumulative effect of two consecutive no - till practices leading to improvements in soil structure and therefore rooting and soil water relations, or simply response to the rainfall regime. The beneficial effects of zero tillage and tied-ridging on sorghum yield varied with differences in amount and distribution of rainfall and fertility management options as observed. Decrease in yield under tied ridging have also been reported in Kenya by Kihara *et al.* (2012) and was attributed to high rainfall. Studies have shown that the positive effect of zero tillage on crop yield is observed after some years (Duiker *et al*., 2011 and Ogle *et al.*, 2012). Contrasting results were obtained by Zougmoré *et al*. (2004) in the Sahelian part of Burkina Faso where the annual rainfall is lower than 800 mm. Tesfahunegn (2012) reported 45% increase in sorghum grain yield under tied ridging practice compared to zero tillage in Abergelle area in northern Ethiopia.

Sorghum performance under different fertility management options could be related to N and P availability to crops, the compost quality and the nutrient release patterns by the compost. Higher yields obtained in compost + fertilizer treatments could be attributed to the nutrients being readily available from the fertilizers and also the improvement of mineralization of the compost with the application of mineral fertilizer as observed by Zougmore *et al.* (2003). In compost treatments, nutrients availability depends on nutrient concentration and release in synchrony with crop needs (Bationo *et al*., 2012).

As productivity of most soils in their native state in the study area is very low (Bationo *et al*., 1998), applying plant nutrients (compost, urea and NPK) to these poor soils induced great positive reaction to crop production, particularly during good rainfall years when soil moisture constraint is less (Zougmore *et al*., 2004). In plots with compost application, the mineralization of compost released not only the macro nutrients such as nitrogen and phosphorus but also considerable amounts of micronutrients for plant use (Zougmore *et al*., 2008)

Significant crop response to chemical fertilizer application in this study indicated the importance of fertilizer in the cropping system. Cropping system management should integrate an appropriate tillage system, organic resources, even in small quantities, and the use of mineral fertilizers. This was well demonstrated by Vanlauwe *et al.* (2011) who revealed greater agronomic performance when fertilizer was combined with manure or compost.

CHAPTER FIVE

5.0. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary and Conclusion

The main purpose for the study was to examine the effects of tillage, soil amendment and their interactions on soil chemical and physical properties, nutrient uptake, nutrient utilization efficiency and sorghum yields in order to identify management practices that could reduce water stress and improve soil fertility for sustainable crop production so as to contribute towards increasing the productivity of sorghum based cropping system in the south Sudan agro-ecological zone of Burkina Faso.

Conventional tillage decreased soil bulk density and hence resulted in an increase in total porosity and aeration porosity compared to zero tillage, ripping and conventional tillage practices. The tillage practices did not significantly affect soil structural degradation index (StI) values but a decrease tendency of StI was observed under Ripping, Tied-ridging and conventional tillage practices compared to the zero tillage. Also improvement in soil stability index under compost application was observed. Ripping improved soil steady state infiltration rate compared to the other tillage practices. The Tied-ridging improved soil saturated hydraulic conductivity leading to an improvement in soil moisture storage. Zero tillage improved soil moisture storage at 0 - 30 cm depth while Tied - ridging improved it at 30 - 50 and 0 - 50 cm depth. Mulching improved soil moisture storage compared to the Control. The Compost application led to an increase in soil organic carbon content.

The Tied - ridging by storing more moisture decreased soil ammonium – N content by favouring the nitrification process. During the peak rainfall period (September), the ammonium - N content decreased under Tied-ridging and Conventional tillage practices while it increased under Ripping and Zero tillage practices. Tied ridging and conventional tillage improved sorghum plant P uptake. The combined application of compost and mineral fertilisers improved soil organic carbon, total nitrogen, total phosphorus and total potassium contents.

A decrease in N and P utilization efficiency was observed under Conventional tillage compared to Zero tillage and Ripping practice. Furthermore, the application of NPK and compost + urea + NPK reduced the dry matter production per unit of nutrient absorbed.

Tied - ridging and Conventional tillage increased sorghum yield only in 2012. Compost + mineral fertiliser application improved both sorghum grain and biomass yields compared to the Control, Mulching, Compost and NPK + urea application. In the context of climate change, Tied-ridging which did not work 20 years ago due to high rainfall is now suitable under declining rainfall in the south Sudan zone.

Key findings

- Soil moisture storage is more related to the hydraulically functioning pore size and distribution than total porosity.
- Aeration porosity is more sensitive to tillage practices than total porosity.
- Tied-ridging which did not work 20 years ago due to high rainfall is now suitable in the south Sudan zone.

5.2. Recommendations

In order to sustain crop production on the sandy loam soils in the South Sudan zone which are low in nutrients and water holding capacity, farmers need to adopt tillage practice that improves soil moisture. In the Increasing performance the recommended tillage practices are Tied-ridging > Conventional Tillage.

A combined use of water conserving tillage practices and soil amendments is recommended to ensure higher grain yield on farmer's field. The preferred options of the amendments are in the order of Compost + NPK + Urea > NPK + Urea > Compost. The preferred integrated options are zero tillage x Compost + NPK + Urea and Tied ridging x Compost + NPK + Urea.

Further studies are recommended for pore size and its distribution under different tillage treatments as they relate to soil moisture conservation as well as impacts on field water balance. The impact of the interacting soil amendments and tillage on soil water dynamics in relation to sorptivity, hydraulic conductivity, nutrient uptake by crops and leaching, particularly nitrogen need in depth research attention to elucidate the operational mechanisms.

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APPENDICES

Appendix 1 : Mixed models analysis for soil ammonium - N

Fixed term	Wald statistic	d.f.	chi pr
Time	14.89	3	0.002
Tillage practice	9.34	3	0.025
Fertility management	1.29	4	0.863
Time x tillage practice	11.14	9	0.266
Time x fertility management	14.64	12	0.262
Tillage practice x fertility management	28.55	12	0.005

Appendix 2: Mixed models analysis for soil nitrate - N

Fixed term	Wald statistic	d.f.	chi pr
Time	13.59	3	0.004
Tillage practice	13.92	3	0.003
Fertility management	8.94	4	0.063
Time x tillage practice	14.52	9	0.105
Time x fertility management	6.62	12	0.881
Tillage practice x fertility managenent	12.71	12	0.391

Appendix 3: Mixed models analysis for soil total mineral N

Fixed term	Wald statistic	d.f.	chi pr
Time	28.99	3	<0.001
Tillage practice	3.90	3	0.272
Fertility management	4.22	4	0.376
Time x tillage practice	5.63	9	0.777
Time x fertility management	9.93	12	0.622
Tillage practice x fertility management	16.00	12	0.191