INTEGRATED MANAGEMENT OF COMPOSTED CATTLE MANURE AND MINERAL FERTILIZER FOR IMPROVED PEARL MILLET AND COWPEA YIELDS UNDER STRIP CROPPING SYSTEM IN NIGER

BY

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A Thesis submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, in partial fulfillment of the requirements for the award of degree of

DOCTOR OF PHILOSOPHY IN SOIL SCIENCE

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BSc. Agriculture (2008)

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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 acknowledgement has been made in the text.

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DEDICATION

This work is dedicated to my late father who I lost since primary school. Your spirit and wisdom strengthen me everyday of my life, may ALLAH accept you in paradise forever; my dear mother for the education I received from her and her moral and financial support unabated, mum, may Allah bless you; my wife Safia Illiassou Mahamane who supported me and endured the pains caused by my long absence from home; my son ABOUBACAR-SIDIK who joined me and strengthened me in the course of this work.

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ABSTRACT

Soil fertility decline due to low nutrient input is a constraint to increasing crop production in smallholder cropping systems in Niger. The current rate of fertilizer application is insufficient for replenishing soil fertility and to compensate for nutrient removal. Organic amendments provide most of the essential nutrient elements, but limited availability and contrasting qualities restrict the supply of sufficient quantities to meet crop demand. This study therefore aimed at enhancing the yields of improved pearl millet and cowpea through the sole and integrated use of compost and mineral fertilizer. Compost was prepared using manure and cowpea haulm. Decomposition and nutrient release patterns of the matured compost were monitored under field conditions using litterbags. The optimum combinations of compost and mineral fertilizer for optimal millet and cowpea yields were assessed over a two-year field experiment during the 2013 and 2014 cropping seasons. The treatments used consisted of a factorial combination of (i) three levels of compost (0, 2500 and 5000 kg ha^{-1}) and (ii) four levels each of two mineral fertilizer types (0, 100, 175 and 200 kg ha^{-1} NPK for millet and 0,

50, 75 and 100 kg ha^{-1} DAP for cowpea). The treatments were arranged in Randomize Complete Block Design (RCBD) with three replications. Composting manure resulted in 2.5 and 4.5 times more N and P contents respectively. Decomposition results after 84 days revealed that 40.3 and 56.5 % of compost mass losses were recorded respectively in 2013 and 2014 cropping seasons. In 2013, 31, 74 and 97 % of N, P and K, respectively were released at 63 days of decomposition. On the other hand, peak N, P and K release values of 58, 60 and 99 % respectively were obtained after 84 days of decomposition under field conditions in 2014. The application of 2500 kg ha^{-1} of

compost resulted in an increase of pearl millet and cowpea grain yields of 11 and 26 %, respectively over the 2 cropping seasons compared to the application of recommended rate of mineral fertilizer. Doubling the rate of compost from 2500 to 5000 kg ha^{-1} did not result in any additional increase in yield of millet and cowpea. Combined use of compost and mineral fertilizer markedly improved some millet and cowpea growth parameters (crop growth rate and leaf area index) which resulted in an increase in grain and straw/haulm yield. Sustainability yield index (SYI) was greatest on plots which received the combined application of compost and mineral fertilizer. Application of compost at 2500 kg ha^{-1} + 175 kg ha^{-1} NPK and 5000 kg ha^{-1} + 175 kg ha^{-1} NPK which produced higher SYI values of 0.64 and 0.65 respectively, appeared to be more promising in sustaining millet production. Similarly, application of 5000 kg ha^{-1} compost combined with 50 and 75 kg ha^{-1} DAP gave higher cowpea SYI of 0.63 and 0.57 respectively. Combined application of compost and mineral fertilizer led to N and P accumulation in the soil which resulted in positive partial N and P balances. On average, N and P use efficiencies for millet were increased by 60 and 31 %, respectively with the application of compost at 2500 kg ha^{-1} + 175 kg ha^{-1} NPK over the control. The highest N and P use efficiencies of cowpea were recorded on plots that received compost at 2500 kg ha^{-1} + 50 kg ha^{-1} DAP. Among all the combined use of compost and NPK fertilizer, application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK gave the highest net return of US $ 366.3 for pearl millet while the highest cowpea net return of US $ 37.5 was obtained under 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP . These findings indicate that pearl millet and cowpea yields could be increased with combined use of compost and mineral fertilizer which may have important implications for combating food insecurity in the Sahel region.

CHAPTER ONE

1.0 INTRODUCTION

In Africa, low growth rate of cereal and grain yield result in widespread malnutrition, recurrent need for emergency food supply and an increasing dependence on food importation (Branca *et al.*, 2011). Indeed this situation is a consequence of low soil fertility, which is a major constraint to increasing food production in Africa (Bationo *et al.*, 2004). This is due to inherent or induced deficiencies of major nutrients such as N, P and K or low nutrient holding capacities, high acidity and low soil organic matter content (Bationo *et al.*, 2006a). Sub-Saharan Africa (SSA) is a large area of Africa where land degradation is seen as a major limiting factor for agricultural production and food security (Saidou *et al.*, 2010b). Niger is one of the poorest countries in the Sahelian zone of West Africa where soil fertility and rainfall are the most limiting factors to crop production. Soils in Niger are generally sandy and low in organic matter, deficient in phosphorus (P) and nitrogen (N) (Baidu-Forson and Bationo, 1992), and low in moisture-retention capacity (Issaka, 2001; Mahaman, 1988). The majority of the people in Niger depend on subsistent agriculture for their livelihood. There is therefore the need for sustainable land use which implies harmony between man‟s use of land and the ability of land to maintain or renew its quality as reported by Fatondji *et al.* (2006).

The use of mineral fertilizer has been proposed to overcome the declining soil fertility and crop production throughout SSA. However, the use of mineral fertilizers in subSaharan Africa is limited by the lack of purchasing power and scarcity of the product in smallholder sectors while their continuous use lead to a decline in soil organic matter (SOM)

(Chivenge *et al.*, 2009). Fertilizer use is very low in Niger with an estimate of 5 kg per hectare (Rinaudo and Yaou, 2009). Despite the introduction of mineral fertilizer in SSA in general and especially in Niger, crop yields are still low. For instance in Niger, average grain yields of cereals under subsistence farmer management remain low, varying from 150 to 550 kg ha^{-1} (Manyame, 2006). Consequently, there is a need to explore the efficient utilization of the available nutrient resources that can lead to improved crop yields. In fact, the potential of genetically improved crops cannot be realized when soils are depleted of plant nutrients. Thus, soil fertility under cultivation can only be maintained by an integrated management of plant nutrients. This management involves efficient recycling of organic materials like crop residues or manure, in combination with mineral fertilizer under improved cropping systems.

In Niger, considerable information is available on the requirements for sole cropping of various crops and several studies have been conducted to assess the effect of combining manure and mineral fertilizer on grain yields under millet/cowpea intercropping system (Garba and Renard, 1991; Kramer *et al.*, 2002; Diangar *et al.*, 2004; Saidou *et al.*, 2010b). However, there is limited information on the use of manure as an alternative to mineral fertilizer for intercropping, although manure application is one of the most effective ways of improving soil fertility. Indeed, mechanisms underlying the integrated use of cattle manure and mineral fertilizer under farmer management are still not well understood. Furthermore, there is still scarce information on the requirement of combined application of cattle manure and mineral fertilizer on improved pearl millet [*Pennisetum glaucum* (L.) R.Br.] and cowpea [*Vigna unguiculata* (L.) Walp] varieties under strip cropping and its effect on soil fertility. The suitability of composted cattle manure to meet the nutritional requirement of crops (millet and cowpea) and its effect on the physicochemical properties of soil and the extent to which subsequent crops can benefit from its application is not well documented. Furthermore, there is also lack of appropriate recommendations on the integrated management of composted cattle manure and mineral fertilizer under strip cropping system.

The overall objective of this study was to optimize the application of composted cattle manure and mineral fertilizer and to enhance yields of improved pearl millet and cowpea varieties under strip cropping system in Niger.

Working on the hypothesis that integrated composted cattle manure and mineral fertilizer under strip cropping system results in high yield of pearl millet/cowpea and efficient use of both amendments, the specific objectives of the study were to:

i. evaluate the decomposition and nutrient release patterns of composted cattle manure;

ii. determine the optimum combination of composted cattle manure and inorganic fertilizer application and their effect on the growth and yield of millet/cowpea under strip cropping system;

iii. assess the sustainability yield index and agronomic efficiency of composted cattle manure and mineral fertilizer (NPK) under strip cropping system, and

iv. evaluate the N and P partial balance of combined application of composted cattle manure and mineral fertilizer under strip cropping system.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Background

Declining soil fertility in smallholder farms is the fundamental biophysical root cause for low per capita food production in sub-Saharan Africa (SSA) (Sanchez, 2002). In fact, soil nutrient mining is one of the main causes of the current stagnation, or even decline in crop yields in the sub-region (Kanté *et al.*, 2007). Current productivity of millet cropping system is very low, with average grain yield rarely exceeding 500 kg ha^{-1} in Africa (Akponikpe *et al.*, 2008). Unfavorable inherent soil fertility as well as frequent droughts and high inter-annual rainfall variability are some of the reasons for low yield. In semi-arid sub-Saharan Africa, it is usual to find great variability in rainfall and low accessibility to technical information and markets, so the early and widespread adoption of fertilizers has not occurred (Kihanda *et al.*, 2007). This situation largely contributes to poverty and food insecurity in the whole region. To deal with this situation, an alternative approach must be found to replenish soil fertility depletion. Manure application is one of the most effective ways for improving soil fertility in SSA. Therefore, combined application of mineral fertilizers and organic resources has been proposed as an appropriate strategy to ameliorate soil fertility decline and improve productivity as reported by Kihara *et al.* (2007).

2.2 Soil fertility problems in Africa

For the West African Sahel in particular, scientists have demonstrated that above an average annual precipitation of 250 mm, SOM and limited availability of plant nutrients, particularly phosphorus (P) and nitrogen (N), are major bottlenecks to crop production (Schlecht *et al.*, 2006). Hanson (1992) reported that of the three billion hectares of arable land in tropical Africa, only 14.7 % is considered to be free of physical or chemical constraints. One third (32.2 %) has physical constraints, 13.2 % has limited nutrient retention capacity, 16.9 % has high soil acidity, and 6.8 % has high P fixation. Also, human based and physico-climatic factors are among principal factors affecting soil productivity potential of soil resources in SSA (Sanchez *et al.*, 1997). Soils in Africa are typically highly variable in fertility and in how they respond to inputs (Hossner and Juo, 1999). Most soil resources in Africa exhibit low nutrient levels with a high propensity towards nutrient loss due to their fragile nature (Bationo *et al.*, 2006a). Indeed poor soil fertility and nutrient depletion continue to represent huge obstacles to achieve the needed food production in SSA and to push out hunger and food insecurity away from the region (Sanginga and Woomer, 2009). Thus, better soil fertility management is imperative for SSA because soil fertility depletion on smallholder farms is seen as the fundamental biophysical root cause of declining per capital food production in Africa (Sanchez *et al.*, 1997). Consequently, the need to effectively manage soil resources in order to achieve optimum productivity of soils is obvious. On the other hand, improving local agricultural production and ensuring adequate supply to the general populace is a vital step in preventing a total collapse of the food production and supply sector of the economies of developing countries of SSA (Chukwuka, 2009). Soils in Niger are generally sandy, low in organic matter and moisture-holding capacity, and deficient in both P and N, although P tends to be more limiting to crop productivity reported Abdoulaye and Sanders (2005). Therefore better technologies, more sustainable practices, improved seeds and fertilizers to increase and sustain crop productivity and to prevent further agricultural land degradation are expressly needed in SSA, particularly in Niger where 90 % of the population depends entirely on agricultural production for their livelihood. Proper soil fertility management becomes imperative when considering issues regarding soil fertility improvement in SSA.

2.3 Soil nutrient depletion

Soil fertility depletion is a major problem in many areas of SSA and contributes, along with other factors, to low and declining agricultural productivity and food insecurity in SSA. Unsustainable land cultivation practices like inadequate replacement of soil nutrients taken up by crops have led to accelerated depletion of the natural soil base available for food production. The magnitude of nutrient depletion in Africa"s agricultural land is enormous and is becoming a serious concern for all stakeholders (Smaling, 1993). Sanchez *et al.* (1997) reported that an average of 660 kg N ha^{-1}, 75 kg P ha^{-1}, and 450 kg K ha^{-1} have been lost during the last 30 years from about 200 million ha of cultivated land in 37 African countries. This is equivalent to 1.4 t of urea ha^{-1}, 375 kg of triple superphosphate (TSP) ha^{-1} or 0.9 t of phosphate rock (PR) ha^{-1} of average composition and 896 kg of potassium chloride (KCl) ha^{-1} during the same period. Also, poor cultivation practices have resulted in a decrease of soil fertility, reduction of SOM and increase in occurrence of acidified soils (Aihou *et al.*, 1998). Indeed, low soil fertility inevitably leads to low agricultural productivity, since agricultural development is fundamentally affected by productivity status of land resources.

Soil nutrient mining in Niger was estimated to average 15 kg ha^{-1} of N, 2 kg ha^{-1} of P, and 11 kg ha^{-1} of K per year, equivalent to an annual loss of about 440 kg of millet grain and 1,860 kg of straw per hectare as reported by Pender *et al.* (2008). As a consequence, yields are low, typically less than 500 kg ha^{-1}. Therefore, soil productivity maintenance remains a major vital and environmental issue in countries of SSA (Oyetunji *et al.*, 2001) especially in Niger.

2.4 Nutrient replenishment

One of the eight agronomic laws stated that for the maintenance of soil fertility, most of the nutrients removed from soil through harvests (crop uptake) must be returned (Sebillotte, 1974). Indeed nutrient inputs to soils cultivated by small-scale farmers are essential for improved crop production in Africa. Some best ways to replenish soil nutrients are through inorganic and organic amendment application which can improve soil nutrient status and maintain soil organic matter content.

2.4.1 Effect of amendments on soil fertility and crop production

Continuous soil fertility decline is the major problem limiting crop production in SSA and particularly in Niger. There is a need to amend soil using several amendment sources so that it continues to support crop production with minimum soil fertility decline. In the sahelian zone of Africa, where farmers use very little or no inorganic fertilizers due to their high prices, organic amendments constitute the principal source of nutrients for sustainable agriculture. This can help to improve soil productivity and meet the need of the growing population in Africa.

2.4.1.1 Use of inorganic fertilizer

Since the 1970s, research throughout West Africa showed that low soil organic matter and limited availability of plant nutrients, in particular phosphorus and nitrogen were the main constraints to food production in this area (Schlecht *et al.*, 2006). Crop response to N is minimal until P requirements have been satisfied and P seems to be the most limiting plant nutrient in SSA. On average, less than 5 kg ha^{-1} of mineral fertilizer nutrients are applied to food crops in sub-Saharan Africa, the lowest rate in the world (Quiñones *et al.*, 1997). To overcome low soil productivity, mineral fertilizers have been proposed as an alternative. With the introduction of mineral fertilizers, some increases in yields have been observed throughout West Africa depending on the agro-ecological setting (soil types and rainfall) and the rates and frequencies of applying these amendments. Nevertheless, the high cost of fertilizers, lack of credit, delays in the delivery of fertilizers and poor transport and marketing infrastructure serve as disincentives to fertilizer use by smallholder farmers (Buresh and Giller, 1998). As a result, fertilizers are sparsely used, grain yields and per capita food production are declining, and food insecurity is worsening, particularly in the extensive semi-arid areas of Africa. Buerkert *et al.* (2001a) showed that NPK placement (considering P alone) at 0.4 g P per hill raised average cereal yields between 26 and 220 % in 1998 across eight locations in Niger, Burkina Faso and Togo. This revealing P placement is a promising strategy to overcome P deficiency as the regionally most growth limiting nutrient constraint to cereals. Also they demonstrated that the average total dry matter (TDM) yield in P placed plots was 672 kg ha^{-1}, which was 120 % higher than the average control (Po) plots confirmed by the second set of on-farm test in 1999 where average yield increases of 118 % for NPK and 116 % for DAP were found. Hussein *et al.*

(2011) showed that under irrigation, NPK fertilization improved either fresh or dry matter yields of pearl millet by 42.24 % (fresh yield) and by 56.71 % (dry matter yield) by applying 60 kg N + 32 kg P_2O_5 + 48 kg K_2O in Egypt. This result indicates that pearl millet yield responded positively to NPK application. From the two - year on-farm trials conducted in Burkina Faso, Mali and Niger, Tabo *et al.* (2007) showed that, on average in all the three countries, grain yields of millet and sorghum were greater by 44 to 120 % while incomes of farmers increased by 52 to 134 % when using hill application of fertilizer than with the earlier recommended fertilizer broadcasting methods and farmers‟ practice. Although mineral fertilizer application increase yields, its use alone cannot stand up to address continuous soil fertility decline problem. Hence, the necessity of having sources of organic amendments more especially because most soils are sandy in SSA and are subject to water and wind erosion. They should be amended with organics before applying mineral fertilizers to avoid greater losses through leaching and water erosion.

2.4.1.2 Use of organic manure

Organic inputs have several advantages in soil fertility management. Apart from providing essential plant nutrients, they contribute directly towards the build-up of SOM and its associated benefits (Fairhurst, 2012). In fact manure, one of the key inputs to smallholder farming systems, especially in the semi-arid environment of SSA where cost and availability limit the use of inorganic fertilizers, it is used to address soil fertility problem. Indeed in the mixed farming systems that characterize SSA, low rural incomes, high cost of fertilizers, inappropriate public policies and infrastructural constraints prevent the widespread use of inorganic fertilizers (Bationo *et al.*, 2004). Many smallholder farmers in SSA, practicing mixed farming, rely on manure to maintain soil fertility and enhance crop productivity; and manure has been long recognized as one of the most effective ways of improving soil fertility and crop production in tropical African conditions (Onduru *et al.*, 2008). Organic sources of plant nutrients such as manure remain the principal sources of nutrients for soil fertility maintenance and crop production. Manure serves as an excellent source of both primary and secondary nutrients required for crop growth. In addition, application of manure improves overall soil quality (physical, chemical, biological properties and moisture holding capacity) which has indirect benefits to the farmer through improved crop response (Akponikpe *et al.*, 2008). Fatondji *et al.* (2006) showed that increasing the rate of cattle manure application from 1 to 3 t ha^{-1} increased yield by 115 % TDM, but increasing the manure application rate further from 3 to 5 t ha^{-1} only gave an additional 12 % yield increase. The average application (total amount of manure applied per landholding) was around 4 t ha^{-1} (Harris and Yusuf, 2001) and this application rate can add approximately 12 kg N, 8 kg P, 32 kg K, 10 kg Mg and 34 kg Ca ha^{-1}. Furthermore, with good rainfall (672 mm), grain yields of maize were high even for the control plots (average 1.2 and 2.7 t ha^{-1})

(Ncube *et al.*, 2006). Also, maize grain yields due to manure applications at 3 and 6 t ha^{-1} were 1.96 and 3.44 t ha^{-1}, respectively. Thus, Abunyewa *et al.* (2007) demonstrated that manure application increased maize grain yield, but doubling manure application did not result in corresponding significant yield increase. In fact, continuous manure application on the same plot each year showed an increased yield of maize as compared to the previous year. Broadcasting manure yielded more than spot application and generally manure broadcast plus fertilizer out yielded manure spot placement plus fertilizer. In the same way, Akponikpe *et al.* (2008) demonstrated that manure application at 900 and 2700 kg ha^{-1} increased millet stover yield by 23 and 27 % and millet grain yield by 19 and 29 % respectively in the sahelian condition of Niger. According to Onduru *et al.* (2008), the potential of manure production under farmer management varied between 0.7 and 3.1 tones dry matter per year per farm at Mbeere and Kiambu districts of Kenya respectively. This shows that optimum application rates of manure around 3 t ha^{-1} results in high millet yield of both grain and stover. In addition, Abunyewa *et al.* (2007) demonstrated during a three year study in northern Ghana that increased maize grain yield as a result of 4 t ha^{-1} manure applied over the control treatment were 55.6 % in 1996, 132 % in 1997 and 121 % in 1998. Doubling manure application rate to 8 t ha^{-1} resulted in increase over control by 67.6 % in 1996, 133 % in 1997 and 225% in 1998. Also they showed that manure application alone explained 40, 39 and 37 % of the variation in maize grain yield in 1996, 1997 and 1998, respectively.

Manure application results in reduction of inorganic inputs such as fertilizers, liming materials, and pesticides, and reduced soil and water losses. Thus, the use of organic manure to meet the nutrient requirement of crops would be one of the inevitable practices in the years to come for sustainable agriculture (Nwaiwu *et al.*, 2010). This leads to enhanced crop productivity and sustains the quality of crops produced (Premsekhar and Rajashree, 2009), even though organic manure contains plant nutrients in small quantities as compared to inorganic fertilizers. Total nitrogen content of manure on dry matter basis ranges from below 0.5 to over 4 % (Paul *et al.*, 2009) and nutrient and carbon losses during manure collection and storage vary substantially. Indeed depending on cattle and manure management, nitrogen losses for example may vary from less than 10 to about 90 % (Paul *et al.*, 2009). According to Eghball *et al.* (1997), nitrogen loss during composting ranged from 19 to 42 % and was related to the initial manure N content. Mass loss was relatively low (15 - 20 %) while C loss ranged from 46 to 62 % and was basically decomposed through bio-oxidation. This mass loss was lower than the normal range of 35 to 50 %. A research survey conducted in one hundred households in Niger, indicates that only 2 % of farmers improved the quality of manure before using it (Abdoulaye and Sanders, 2005). Composting is one of the strategies for enhancing nutrient content of manure by adding some materials rich in nutrient. According to Stoffella *et al.* (1997), composted manure has multiple benefits on both the improvement of the soil and crop performance. As a soil fertility amendment, it can be used as a source of soil nutrients as well as mulch to moderate soil temperatures. Composted manure provides alternative weed control and/or can be used in an integrated weed management programme (Ondieki *et al.*, 2011). Composted manure is generally environmentally friendly. In cases where composted manure could be nutrient deficient due to the type of raw materials used, artificial fortification can be done by adding the deficient nutrient hence ensuring its appropriateness. The way farmers handle manure traditionally (by leaving it under sun for instance) does not allow them to see improvement in their production. Moreover, the type of compost farmers use is either from domestic premises which could have variable nutrient contents or deficient (Jost *et al.*, 2013) depending on the raw materials and methods used during composting; hence the need for fortification to make them more appropriate.

2.4.1.3 Factors influencing manure mineralization

The mineralization of manure is governed by biological, chemical, and physical properties of soil and is a function of the chemical composition or quality of the organic manure, soil moisture, and soil temperature (Eghball *et al.*, 2002). Manure mineralization is a process where microbes digest and reduce the organic portion of the manure to inorganic materials. Inorganic materials released during this process are the essential plant macronutrients (N, P, and K), micronutrients, salts, and heavy metals.

Soil moisture, temperature, and aeration regulate soil microbial activity, and thus are factors that influence the rate of manure mineralization. Soils that are warm, moist, and well aerated have the highest potential rate of organic manure mineralization. Lower potential rates should be expected when soils are dry, cold, or saturated with water (Watts *et al.*, 2007; Azeez and Van Averbeke, 2010).

2.4.1.4 Integrated organic and mineral fertilizer management

The combined application of organic resources and mineral fertilizers is increasingly gaining recognition as one of the appropriate ways of addressing soil fertility depletion, especially in low-external input systems in SSA and forms an integral part of integrated soil fertility management (Vanlauwe *et al.*, 2010). Indeed food production can be increased through the integration of organic and inorganic nutrient sources coupled with proper land and crop management. Researchers showed that productivity of sandy soils can be increased significantly with the adoption of improved crop varieties, cropping systems and combined use of organic and inorganic fertilizers. For instance, application of animal manure and retention of crop residues in the field are nutrient recycling processes that culminate in increased soil organic matter, pH, exchangeable bases, improved soil structure, and reduced capacity of soils to fix P (Baldock and Musgrave, 1980; Bationo and Mokwunye, 1991). Furthermore, integrated use of organic and inorganic resources under intercrop is superior to inorganic fertilizer only. For example, application of 8.5 kg N ha^{-1} increased maize grain yields up to 2.5 t ha^{-1} with 3 t ha^{-1} of manure, and to 4.3 t ha^{-1} with 6.0 t ha^{-1} of manure (Ncube *et al.*, 2006). In addition, the use of 75 % of NPK recommended rate (RR) + 5 t of farmyard manure improved the seed yield of soybean by 47 % and 32 % over the use of 75 % of NPK RR in sole and intercrop systems respectively (Ghosh *et al.*, 2004). On the other hand, Akponikpe *et al.* (2008) demonstrated that combining 2700 kg ha^{-1} of manure + 300 kg ha^{-1} of crop residues (millet straw) and 900 kg ha^{-1} of crop residues + 15 kg N and 4 kg P ha^{-1} increased pearl millet grain yield by 95 % and 132 % respectively. In fact, combining manure and mineral fertilizer or even crop residues can result in an additive effect of both amendments. However, high amount of manure (2700 kg ha^{-1}) and fertilizer (45 kg N and13 kg P ha^{-1}) leads to no additional yield increase or even to a yield decrease (Akponikpe *et al.*, 2008). Adamou *et al.* (2007) demonstrated that by integrating organic and mineral fertilizer**,** the absolute control recorded 79 kg ha^{-1} of pearl millet grain yield; 1267 kg ha^{-1} was obtained when phosphorus, nitrogen and crop residue were applied and followed cowpea of the previous season. Results indicated that for total dry matter yield, phosphorus use efficiency (PUE) increased from 126 kg $ha^{-1}$with only P application to 228 kg ha^{-1} when P applied in combination with nitrogen plus crop residue and to 318 kg ha^{-1} in a rotation system. Cowpea fodder production was increased to 1267 kg ha^{-1} in the rotation system while the grain production was low and variable with a highest yield of only 213 kg ha^{-1} (Adamou *et al.*, 2007). A three-year study in northern Ghana showed that percent increases in maize grain yield due to manure plus fertilizer over fertilizer application only ranged from 64 to 75 % in 1996, 59 to 69.5 % in 1997 and 43 to 66.8 % in 1998 (Abunyewa *et al.*, 2007). Furthermore, combinations of mineral N fertilizer with the leguminous resources and manure resulted in between 24 and 104 % increase in grain yield of maize against sole fertilizer, implying an increased nutrient recovery by maize under organic - inorganic combinations (Mtambanengwe *et al.*, 2007). According to Efthimiadou *et al.* (2010), combined use of NPK and farmyard manure increased SOM, total N, Olsen P and exchangeable K by 47, 31, 13 and 73 % respectively compared to application of NPK through inorganic fertilizer. Intercropping legumes and cereals with the addition of mineral fertilizer or organics has been reported to improve yield and incomes of farmers. Thus, Haseeb-ur *et al.* (2010) showed that maize intercropped with cowpea with the addition of N at 225 kg ha^{-1} gave higher grain yield of 6.65 and 1.26 t ha^{-1} of maize and cowpea respectively. Also, higher net farm income and cost benefit ratio with maize intercropped with cowpea and N at 225 kg ha^{-1} was obtained (Haseeb-ur *et al.*, 2010). Yamoah *et al.* (2003) demonstrated that returns from cowpea grown in cowpea-millet rotation without fertilizer and rates of fertilizers (4 kg P ha^{-1} + 15 kg N ha^{-1}) were found to be most profitable in terms of high returns and low risk, principally because of a higher price of cowpea than millet.

2.5 Constraints to mineral fertilizer and organic resources use

In spite of the importance of mineral fertilizer and organic resources for soil fertility management, nutrient supply and improvement of crop production, there are still some constraints in their use.

2.5.1 Constraints to mineral fertilizer use

Despite the fact that farmers are aware that maximum yield can be obtained by using mineral fertilizers, they use very little amount due to some reasons. Throughout Africa, sufficient mineral fertilizers are not available at the right time during the year. Shortage, high cost, incorrect type, adulteration of fertilizer and farmer‛‛s unfamiliarity and incorrect usage of fertilizer are some reasons that impair fertilizer widespread use in Africa (Sanginga and Woomer, 2009). Also at the beginning of fertilizer introduction, focus was on cash crops and the recommendations were blanket instead of being specific. Furthermore, farmer‛‛s resource endowment, access to credit, farm
characteristics are also key determinants for mineral fertilizer use. In fact, yield varies widely with the climate: rainfall is highly uncertain; in drought years the crop response to fertilizer can be very low. Mineral fertilizers do not improve soil physical structure or enhance soil biological activity (Odhiambo and Mag, 2008).

In Niger, the fertilizer price relative to the millet price is a highly significant determinant of fertilizer adoption (Abdoulaye and Sanders, 2005). Other studies in semi - arid regions have emphasized on risk, liquidity, or fertilizer responsiveness as constraint to fertilizer use.

2.5.2 Constraints to organic resources use

The use of organic resources for soil fertility improvement in SSA has been in practice for a long time. Indeed even though organic resources have been claimed by scientists as an alternative for soil fertility restoration, several constraints reduce their widespread use. The major constraint of organic inputs is their relatively low nutrient content (Fairhurst, 2012). Organic inputs are therefore required in large quantities if they are to supply significant amounts of nutrients to growing crops. Such large biomass quantities are, however, not always easy to find in resource-constrained smallholder farming systems. Also, the use of organic resources require huge labour force for both processing and transporting, as well as large amounts of organic resources often needed to supply adequate nutrients to soils for successful crop production (Chukwuka, 2009). In fact, the availability of organic resources as nutrient sources is limited by their alternative use as fuel, feed and fibre (Sanginga and Woomer, 2009).

2.6 Cropping systems and their effect on soil fertility and crop production

Another way of dealing with continuous food production decline observed within SSA is growing crops under different cropping systems. Yamoah *et al.* (2003) showed that choice of cropping systems explained more than 50 % of the overall variability in millet and cowpea grain yields. Indeed, the most common cropping systems in SSA are monocropping, crop rotation and intercropping. The use of different cropping systems provide farmers with several options for returns and prevents uncertain sahelian conditions. It increases the efficient use of scarce resources and reduces dependence upon a single crop that is susceptible to environmental and economic fluctuations. In the sahelian zone, the cropping system is millet-based, with millet/cowpea and millet/groundnut being the important cropping patterns.

2.6.1 Monocropping system

Monocropping system is the agricultural practice of growing a single crop year after year on the same land, in the absence of rotation through other crops. While economically a very efficient system, allowing for specialization in equipment and crop production, monocropping is also controversial, as it can damage the soil ecology (including depletion or reduction in diversity of soil nutrients) and provides an unbuffered niche for parasitic species, increasing crop vulnerability to opportunistic insects, plants, and microorganisms (Peter and Runge-Metzger, 1994). The result is a more fragile ecosystem with an increased dependency on pesticides and

artificial fertilizers. Continuous cropping with inadequate nutrient replenishment through the use of mineral fertilizers and cattle manure can lead to soil fertility decline over time.

2.6.2 Crop rotation

Crop rotation is the practice of growing two or more crops in the same space in sequence or a definite sequence of crops grown in successive years (or successive seasons). It can maintain soil fertility by improving soil structure and enhancing soil quality as crop residues improve the quality of the soil organic matter, particularly with regard to leguminous plant that add nitrogen via biological nitrogen fixation (BNF) (Bationo *et al.*, 2003). Crop yields have also been shown to increase substantially using rotation of cereals with legumes or intercropping. Yamoah *et al.* (2003) reported that among the cropping systems, rotation gave higher yields than sole crop and intercropping systems and increased millet yield by 46 % without fertilizer application. Yields of pearl millet can be doubled following cowpea as compared to continuous pearl millet cultivation (Adamou *et al.*, 2007). Also they found that rotation of cereals with legumes could be a way to increase nitrogen use efficiency (NUE) from 20 % in the continuous cultivation of pearl millet to 28 % when pearl millet was rotated with cowpea. In addition to increasing yields of succeeding cereals, rotation has other advantages such as providing good quality livestock feed, which leads to production of manure as organic soil amendment and also provides cash to ameliorate farmer‟s livelihood and their capacity to buy fertilizers. The rotation of legumes with cereals will give more opportunity to increase the legume component in the present cropping systems.

2.6.3 Intercropping system

Intercropping is an alternative pathway for sustainable agriculture in Africa. Traditional intercropping systems, the agricultural practice of cultivating two or more crops in the same space at the same time, is an old and commonly used cropping practice which aims to match efficiently crop demands to the available growth resources and labor (Lithourgidis *et al.*, 2011). Intercropping is being looked at as an efficient and most economical production system as it does not only increase the production per unit area and time but also improves the resource use efficiency and economic standard of farmers in SSA. Presently, interest in intercropping is increasing and fast becoming important among the small-scale farmers throughout SSA and in Niger particularly because of their diversified needs and low farm income from mono-cropping system. The most common advantage of intercropping is the production of greater yield on a given piece of land by making more efficient use of the available growth resources using a mixture of crops of different rooting ability, canopy structure, height and nutrient requirements based on the complementary utilization of growth resources by the component crops.

Traditional multiple cropping systems are estimated to still provide as much as 15 - 20 % of the world‟s food supply (Altieri, 1999). In Latin America, farmers grow 70 - 90 % of their beans with maize, potatoes and other crops, whereas maize is intercropped on 60 % of the maize-growing areas of the region (Francis, 1986). Other quantitative evaluations suggest that 89 % of cowpea in Africa are intercropped, 90 % of beans in Colombia are intercropped and the total percentage of cropped land actually devoted to intercropping varies from a low 17 % for India to a high of 94 % in Malawi (Vandermeer, 1992).

Several types of intercropping systems have been tested by scientists (Ghosh *et al.*, 2004; Diangar *et al.*, 2004; Ajeigbe *et al.*, 2007; Sarr *et al.*, 2008; Saidou *et al.*, 2010a). Saidou *et al.* (2010a) demonstrated that intercropping four lines of cowpea followed by four lines of millet does not disturb millet biomass and keeps it stable while cowpea biomass increases with increase in crop density in the sahelian zone of Niger. Oseni (2010) demonstrated that intercropping sorghum with cowpea at 2S:1C planting pattern will give higher income, better land use efficiency and thus enhance sustainability of crop production than sole culture of each crop species at Bauchi in the northern Guinea savanna of Nigeria. Intercropping systems, especially a cereal-legume combination have the potential to achieve higher grain yield and greater land use efficiency than sole cropping. Thus, it helps in minimizing the risks of uncertain crop production and brings stability under rainfed condition. Ghosh *et al.* (2004) reported that the grain yield of intercropped sorghum (with soybean) was 9.5 % more than sole sorghum.

2.7 Composting

2.7.1 Composting process

Composting is a naturally occurring process that farmers have used for centuries. Under the right conditions, microorganisms grow and multiply and decompose the organic material by converting its original form into a more stable, usable product. Farmers manage the organic resource through composting to obtain the same product that should occur naturally but much more quickly. Composting is the active management of manure, crop residues and litter to aid the decomposition of organic material by microorganisms under controlled conditions (Augustin and Rahman, 2010). According to Sandeen and Gamroth (2003), effective composting is affected by four major factors:

i. Aeration, is a key element in efficient composting. Composting is an aerobic process meaning that it requires lots of oxygen. Air can be provided by stirring and mixing the material in the pit. ii. Nutrient balance, determined by the ratio of carbon to nitrogen in the compost pile.

The ideal C:N ratio is 25:1 to 30:1 iii. The moisture content of the compost pit ideally should be around 60 % after the original mixing, below 40 % the decomposition decreased rapidly and

iv. The temperature, which is expected to increase in a compost pile due to the breakdown of the organic material by microorganisms. It can reach 65.5 ^{0}C in less than 2 days and the maximum composting rate occurs when temperature is between 37.8 – 65.5 ^{o}C.

Furthermore, Ewusi–Mensah (2009) reported also that composting processes typically have three main stages:

a. A mesophilic growth stage, which is characterized by bacterial growth under temperatures of 25 – 40 ^{o}C;

b. A thermophilic stage, where bacteria, fungi and actinomycetes (first level consumers) functioning at temperatures of 50 – 60 ^{o}C, breakdown cellulose, lignin and other resistant materials (this thermophilic stage can go as high as 70^{o}C).

c. A maturation stage, where temperatures stabilize and some fermentation occurs, converting the organic materials to humus (this process commences when the temperature of the composting material reverts to the ambient temperature).

2.7.2 Importance of compost

Compost is considered to be an environmentally safe, agronomically advantageous, and relatively cheap organic amendment which stimulates soil microbial activity and crop growth (Ros *et al.*, 2006). According to Stoffella *et al.* (1997), composted manure has multiple benefits on both the improvement of the soil and crop performance. As a soil fertility amendment, it can be used as a source of soil nutrients (macro and micronutrients) as well as a mulch to reduce soil temperatures. It also improves waterholding capacity, bulk density and biological properties of soil. Composted manure provides alternative for pathogen and weed control, and/or can be used in an integrated weed management program. Composted manures are generally environmentally friendly.

2.8 Major nutrients affecting plant growth and yield

2.8.1 Nitrogen

Nitrogen (N) is the motor of plant growth and constitutes from 1 to 4 percent of the dry matter of the plant. Nitrogen is the key to soil fertility and an essential component of SOM. About 90 - 95 % of the total soil N is associated or combined with the soil organic fraction (Bationo *et al.*, 2006). It is taken up from the soil in the form of nitrate (NO_3^-) or ammonium (NH_4^+). Being the essential constituent of proteins, it is also involved in all the major processes of plant development and yield formation (FAO, 2000). A good supply of nitrogen for the plant is important also for the uptake of the other nutrients.

2.8.2 Phosphorus

Normal plant growth cannot be achieved without phosphorus (Buerkert *et al.*, 2001a). It is a constituent of nucleic acids, phospholipids, and most importantly adenosine triphosphate (ATP). It decomposes carbohydrates produced in photosynthesis; and is involved in many other metabolic processes required for normal growth, such as photosynthesis, glycolysis, respiration, and fatty acid synthesis (FAO, 2000). Phosphorus enhances seed germination and early growth, stimulates blooming, enhances bud set, aids in seed formation and hastens maturity.

2.8.3 Potassium

Potassium is not linked to organic compounds in the plant, and can easily be released from decaying straw becoming available for subsequent crops. The amount of K leached right after drying plant is correlated with the residue nutrient content and can be as high as 64 kg ha^{-1} considering a mulch of 8 t ha^{-1} (FAO, 2000). Although well-nourished millet plants release considerable amounts of K with the first rains, a large percentage of the nutrient is still retained in the straw.

2.9 Summary of literature review

Declining crop production has been noticed many years ago throughout Africa. The main bottleneck of this situation is the continuing decline of the soil"s capacity to ensure its role of nutrient reservoir to crops coupled with low adoption and or misuse of technologies to enhance soil fertility status. Research has struggled to find solutions which are low cost and easily adoptable by farmers in order to reduce food insecurity within the whole of Africa. In light of this, several technologies were developed by researchers. The use of fertilizer to address soil fertility decline and increase crop production had been proposed earlier, followed by the use of organic resources. Despite their advantageous use, some constraints such as high cost, shortage in the market and farmers financial capacity limit the use of fertilizers. Use of organic resources is also limited by their availability and other competing uses (fuel, animal food, building material, etc). To tackle soil fertility problem and to ensure sustainable crop production, research should shift toward integrated use of mineral fertilizer and organic resources. A deep understanding of quality, decomposition and nutrient release pattern of organic resources becomes necessary for their good and efficient use and/or management.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location of the study area

The study was conducted over two years (2013 and 2014) from June to October of each year in Maradi, located in the south central part of Niger republic (West Africa) between 13°-15°26' N and 6°6'-18° 33' E. Maradi region occupies an area of 38,500 km^2, which is approximately 3 % of the total land surface of Niger.

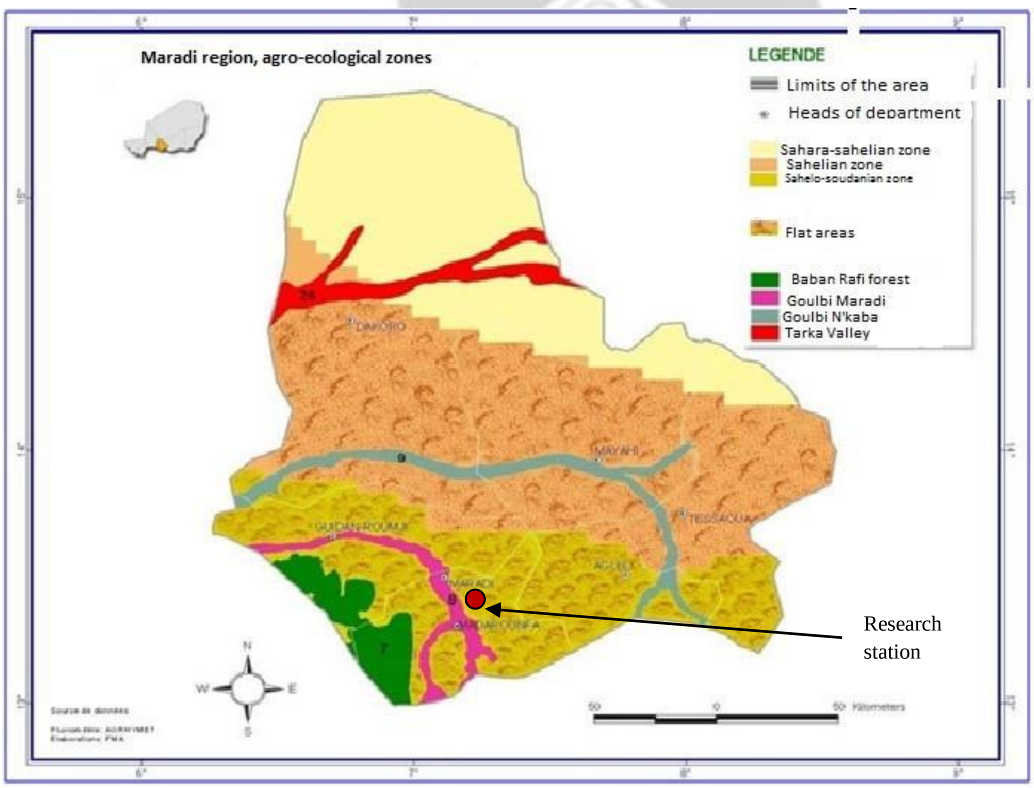

Figure 3.1: Map of the study area

More precisely the experiment was conducted at the National Institute of Agricultural

Research INRAN/CERRA research station. The whole region is within the SaheloSudanian zone, characterized by a monomodal rainfall pattern which is variable and fluctuates between 350 and 650 mm per year with a mean of 500 mm. Rainfall generally exceeds or is equal to potential evapotranspiration for 2 - 4 months.

3.1.2 Climate

The year is characterized by two seasons: the dry season from October to May and the rainy season from June to September. Monthly temperatures are generally high and are at their maximum (around 45 °C) in April/May and in September/October. The cropping calendar is very short; hence, farmers have to use short-duration crops and time their planting to reduce risk of crop failure resulting from inadequate rainfall.

3.1.3 Soil type

The soils of the region are composed of up to 95 per cent sand, and are poor in nutrients and organic matter (Issaka, 2001). Based on parent material, geomorphology and climate, three major soil types have been distinguished:

i. The ferruginous soils, brown color, rich in fine sand in the 0 - 30 cm depth, representing the majority of the soil‟s area and allocated to rainfed agriculture; ii. The Goulbi soils (valley floor), considered hydromorphs, with grey color, rich in silt in the 0 – 30 cm depth and allocated to fruit growing and some vegetable crops;

iii. The iso-humic soils (acid brown soils), advocated to vegetable crops agriculture during the dry season. The majority of Maradi's soils are sandy Arenosols (FAO, 2006) containing very little organic matter (Haglund *et al.*, 2011).

3.2 Planting materials

Improved pearl millet variety, Haini Kiré Précoce (HKP) developed at the National Institute of Agronomic Research of Niger (INRAN) in 1978 with a growth cycle of 75 - 90 days and cowpea variety IT98K-205-8 developed at the International Institute for Tropical Agriculture (IITA), Nigeria with 55 - 57 days growth cycle were used in the field experiment. Pearl millet and cowpea were planted respectively in strip cropping at the density of 1 m x 1 m thinned to 3 plants per hill giving a plant population of 30,000 plants ha^{-1} and 0.5 m x 0.5 m with 2 plants per hill giving 40,000 plant ha^{-1} using 4 rows of millet followed by 4 rows of cowpea (4 M : 4 C) as described by Saidou *et al.* (2010a). Each plot was 6 m wide and 10.5 m long (63 m^2).

3.3 Composting and field experiment

3.3.1 Raw materials used for composting

Manure collected from INRAN/CERRA research station and cowpea haulm from farmers were the raw materials used for composting during the two years of this study (2013 and 2014). Prior to the compost preparation, three samples each of cattle manure and haulm of cowpea were taken in order to characterize the nutrient content of these raw materials.

3.3.2 Compost preparation

The pit method was used for composting. Three pits each measuring 250 cm x 150 cm x 60 cm were dug. Each pit contained 250 kg of cattle manure and 107 kg of cowpea haulm corresponding to 70 % and 30 % of cattle manure and haulm of cowpea respectively. Each pit was watered with 15 L of water followed by the first layer of cowpea haulm (53.5 kg) on which 35 liters of water was added. This was then followed by the first layer of cattle manure (125 kg) and watered with 50 liters of water. The same procedure was used for the second layer of cowpea haulm and cattle manure but with addition of 50 liters of water after each second layer. A total of 200 L of water was used during the compost preparation and at each turning date at least 50L of water was added depending on the compost humidity. Temperature and moisture content of compost were recorded each week. For moisture content, samples were taken and weighed, oven dried at 65 ^{o}C for two days and dry weight was recorded. The moisture content was obtained using the formula:

$$\% \text{ Moisture content} = \frac{(\text{Weight of undried sample} - \text{weight of dried sample}) \times 100}{\text{Weight of dried sample}}$$

For the temperature recording, a small hole was made within the compost pit and a soil thermometer was inserted inside and removed two minutes later for temperature record.

The composting took 67 days in 2013 (from 19th April to 25th June 2013) and 60 days in 2014 (from 7thApril to 16thJune 2014) to mature. At maturity, the compost was air - dried under *Azadirecta indica* tree.

3.3.3 Compost decomposition and nutrient release patterns under field conditions

Litterbags measuring 20 x 30 cm made from nylon mosquito nets with 1.0 mm mesh size were used in the field to monitor the decomposition of compost over time. Each litterbag containing 100 g of matured compost was arranged in a completely randomized block design replicated three times. The litterbags were placed at the same date of compost application within the field. Two litterbags per replication were collected at 3 weeks intervals in 2013 and two weeks intervals in 2014. The remaining compost in the litterbags was weighed after being dried and the weight loss calculated using the formula:

$$\% \text{ dry weight remaining} = \frac{Mt}{Mo} \times 100$$

where:

Mt = mean oven dry weight remaining at time, t

Mo = initial oven dry weight

To describe the decomposition pattern and calculate decomposition rate constants (k), data was modeled using a single exponential model (Olson, 1963) as shown below:

$$M_t = M_0.e^{-kt}$$

Where M_t and M_0 are defined as above, and k is the decomposition rate constant. Several studies have demonstrated that the single exponential model describes reasonably well the decomposition rate of organic resources (Tetteh, 2004; Gnankambary *et al.*, 2008; Ewusi–Mensah, 2009; Fatondji *et al.*, 2009).

For the nutrient release pattern, at each sampling date, a composite sample of 5 g of the remaining compost per litterbag was taken and mixed to obtain a sub-sample of 10 g per replication and analyzed for N, P, K Ca, Mg and organic carbon. Nutrient release was calculated using the equation as described by Gnankambary *et al.* (2008):

$$\text{Nutrient release (\%)} = \frac{Co \times Mo - Ct \times Mt}{Co \times Mo} \times 100$$

where:

Co = initial nutrient concentration of nutrient in compost

Mo = initial mass in the litterbag

Ct = nutrient concentration of nutrient at time t

Mt = mass of compost in litterbag at time t.

3.3.4 Nutrient release patterns of compost under laboratory condition

The leaching tube procedure as described by Fening *et al.* (2010) was used to study the nutrient release patterns of the compost under laboratory conditions. A mixture of 10 g of soil and 1 g of compost was put into leaching tubes plus a control and arranged in a Completely Randomize Design (CRD) with four replications. Samples in the tubes were leached at 3, 6, 9 and 12 weeks in 2013 and at 2, 4, 6, 8, 10 and 12 in 2014 with 100 ml of 1.0 *M* KCl. Nitrate - N (NO_3^-), ammonium - N (NH_4^+), phosphorus, calcium and magnesium were then determined in the leachate. Mineral N was determined using 2 *M* KCl as the extracting solution. Ammonium (NH_4^+) and nitrate (NO_3^-) were determined by steam distillation of ammonia (NH_3) using heavy MgO for NH_4^+ and Devarda‟s Alloy for NO_3^- (Bremner and Edwards, 1965). This distillate was collected in saturated H_3BO_3 and titrated with dilute H_2SO_4.

Calculation:

$$NH_4^+ - N = \frac{(V-B) \times N \times R \times 14.01 \times 1000}{Wt}$$

$$NO_3^- - N = \frac{V\text{-}B \times N \times R \times 14.01 \times 1000}{Wt}$$

where:

V = volume of 0.01 N H_2SO_4 titrated for the sample (ml)

B = blank titration volume (ml)

N = normality of H_2SO_4 solution (N = 0.01)

R = ratio between total volume of the extract and the extract volume used for distillation

W_t = weight of air-dry sample

3.4 Soil sampling and sample preparation

The experimental field was cleared and plots demarcated before the imposition of treatments. Each plot measured 6 m x 10.5 m (63 m^2). Composite soil samples were taken at a depth of 0 - 20 cm before treatments imposition and after harvesting. Within each plot, five samples were taken and mixed to obtain one composite per plot. Thirty six (36) core soil samples were taken from the thirty six plots, bulked after which three subsamples were considered for the initial soil physico-chemical laboratory analysis. After harvesting, thirty six (36) soil samples from all the experimental plots were taken and analyzed for chemical parameters (pH, total N, available P and K, Organic carbon, exchangeable Ca, Mg, K, Na, Al and H). All the samples were air dried, ground, passed through a 2 mm mesh sieve and stored for both chemical and physical analysis.

3.5 Soil laboratory analysis

3.5.1 Soil chemical analysis

The following soil chemical properties: pH, soil organic carbon, total N, available P and K, exchangeable bases were undertaken in the laboratory of the Department of Crop and Soil Sciences, KNUST, Kumasi.

3.5.1.1 Determination of soil pH

The pH of the soil was determined using a Suntex pH mv meter, model 70l at soil: water ratio of 1:1. A 10 g soil sample was weighed into a 50 ml beaker. To this, 10 ml distilled water was added and the suspension was stirred continuously for 15 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 upper part of the soil: water suspension.

3.5.1.2 Determination of soil organic carbon

Soil organic carbon was determined by the modified Walkley-Black wet oxidation method. A 2 g of air-dried soil was weighed into 250 ml Erlenmeyer flask. Then, 10 ml of 0.1667*M* potassium dichromate ($K_2Cr_2O_7$) solution was added to the flask and swirled gently so that the sample was made wet. Using an automatic pipette, 20 ml of concentrated sulphuric acid (H_2SO_4) was dispensed rapidly into the soil suspension and swirled vigorously for 1 minute and allowed to stand on a porcelain sheet for 30 minutes, after which 200 ml of distilled water was added and mixed well. Few drops of diphenylamine indicator were added and the excess dichromate ion ($Cr_2O_7^{2-}$) in the mixture was back titrated with ferrous concentration until the colour of the solution changed to green and the volume used for the titration was recorded. A blank sample was included.

The organic carbon content of soil was calculated as:

$$\% \text{ Organic C} = \frac{(\text{m.e.}K_2Cr_2O_7 - \text{m.e.}FeSO_4) \times 1.32 \times 0.003}{\text{Wt of soil}} \times 100$$

where:

m.e = molarity of solution x ml of solution used

0.003 = m.ewt of C in grams (12/4000)
1.32 = correction factor

wt = weight of soil (2 g)

3.5.1.3 Determination of soil total nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984). A 10 g soil sample was weighed into a Kjeldahl digestion flask and 5 ml distilled water added. After 30 minutes, a tablet of selenium catalyst and 20 ml of concentrated H_2SO_4 were added to the soil and the flask placed on a Kjeldahl digestion apparatus and digested for 3 hours until a clear and colourless digest was obtained. Forty milliliters (40 ml) of distilled water was added to the digest and transferred into 100 ml volumetric flask. Twenty millimeters (20 ml) of 40 % NaOH was also added to the solution and then distilled using the Tecator Kjeltec distiller. The digested material was distilled for 4 minutes and the distillate received into a flask containing 20 ml of 4 % boric acid (H_3BO_3) prepared with PT5 (bromocresol green) indicator producing approximately 75 ml of the distillate. The colour change was from pink to green after distillation, after which the content of the flask was titrated with 0.02 *M* HCl from a burette. At the end-point when the solution changed from weak green to pink the volume of 0.02 *M* HCl used was recorded and % N calculated. A blank distillation and titration were also carried out to take care of traces of nitrogen in the reagents as well as the water used.

The percentage nitrogen in the sample was calculated as:

$$\% N = \frac{(M \times (a - b) \times 1.4 \times mcf)}{w}$$

where:

M= concentration of hydrochloric acid (HCl) used in titration

a = ml HCl used in sample titration

b = ml HCl used in blank titration

w = weight of air-dry soil sample

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

1.4 = 14 × 0.001 × 100 % (14 = atomic weight of N)

3.5.1.4 Determination of soil available phosphorus

The available phosphorus was extracted with Bray No.1 extracting solution (0.03 *M* NH_4F and 0.025 *M* HCl) as described by Bray and Kurtz (1945). Phosphorus in the extract was determined by the blue ammonium molybdate method with ascorbic acid as the reducing agent using a Jenway 6051 colorimeter.

A 5 g soil sample was weighed into a shaking bottle (50 ml) and 30 ml of Bray No.1 extracting solution added. The mixture was shaken for 10 minutes on a reciprocating shaker and filtered through a Whatman No. 42 filter paper. An aliquot of 1 ml of the blank, the extract and 10 ml of the colouring reagent (ammonium molybdate and boric acid) were pipetted into a volumetric flask and uniformly mixed. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a Jenway 6051colorimeter at a wavelength of 660 nm at medium sensitivity.

Calculation:

$$\text{Available } (\text{P mg/kg}) = \frac{(a - b) \times 30 \times 15 \times mcf}{w}$$

where:

a = mg/L P in sample extract

b = mg/L P in blank

mcf = moisture correction factor

30 = ml extraction solution 15 =

ml final sample solution

w = sample weight in gram

3.5.1.5 Determination of exchangeable cations

3.5.1.5.1 Extraction of exchangeable bases

A 10 g soil sample was weighed into an extraction bottle and 100 ml of 1.0 *M* ammonium acetate solution (pH = 7) was added. The bottle with its contents was shaken for thirty minutes. At the end of the shaking, the supernatant solution was filtered through Whatnan No. 42 filter paper and the extract was used for Na, K, Ca and Mg determination.

3.5.1.5.2 Determination of exchangeable calcium

For the determination of calcium, a 10 ml portion of the extract was transferred into an erlenmeyer flask. To this, 10 ml of potassium hydroxide solution was added followed by 1 ml of triethanolamine. Few drops of potassium cyanide solution and cal-red indicator were then added. The mixture was titrated with 0.02 *M* Ethylene Diamine Tetraacetic Acid (EDTA) solution from a red to a blue end point.

3.5.1.5.3 Determination of exchangeable calcium and magnesium

Ten millimeter (10 ml) portion of the extract was transferred into an Erlenmeyer flask and 5 ml of ammonium chloride – ammonium hydroxide buffer solution was added followed by 1 ml of triethanolamine. Few drops of potassium cyanide and Eriochrome Black T solutions were then added. The mixture was then titrated with 0.02 *M* EDTA solution from a red to a blue end point.

Calculation:

$$Ca+Mg \text{ or } (Ca) \quad (cmol_{+}kg^{-1} \text{ soil}) = \frac{0.02 \times V \times 1000}{W}$$

where:

W = weight in grams of soil extract

V = ml of 0.02 *M* EDTA in the titration

0.02 = concentration of EDTA used

3.5.1.5.4 Determination of exchangeable potassium and sodium

Potassium and sodium in the soil extract were determined by flame photometry. Standard solutions of 0, 2, 4, 6, 8 and 10 ppm K and Na were prepared by diluting appropriate volumes of 100 ppm K and Na solution to 100 ml in volumetric flask using distilled water. Flame photometer readings for the standard solutions were determined and a standard curve constructed. Potassium and sodium concentrations in the soil extract were read from the standard curve.

Calculations:

$$\text{Exchangeable K } (\text{cmol}_+ \text{ kg}^{-1} \text{ soil}) = \text{Graph reading} \times \frac{100}{39.1 \times w \times 10}$$

$$\text{Exchangeable Na } (\text{cmol}_+ \text{ kg}^{-1} \text{ soil}) = \text{Graph reading} \times \frac{100}{23 \times w \times 10}$$

where:

w = weight of air-dried sample soil in grams

39.1 = mole of potassium

23 = mole of sodium

3.5.1.5.5 Determination of exchangeable acidity

Exchangeable acidity consists of aluminium (Al^{3+}) and hydrogen (H^+). Five grams (5 g) of soil sample was put into a shaking bottle and 100 ml of 1.0 *M* KCl solution added. The mixture was shaken for one hour and then filtered. Fifty millimeters portion of the filtrate was transferred into an Erlenmeyer flask and 2 - 3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.05 *M* NaOH until the color just turned permanently pink. A few drops of 0.05 *M* HCl were added to the same mixture to bring the solution back to colorless condition and 10 ml of 1.0 *M* sodium fluoride (NaF) solution added. The solution was then titrated with 0.05 *M* HCl until the color disappeared. The milliequivalent of acid used is equal to the amounts of exchangeable Al. The amount of H was determined by difference (McLean, 1965).

Calculation:

$$\text{Exchangeable Al + H or Al } (\text{cmol}_{+}\ \text{kg}^{-1}\ \text{soil}) = \frac{0.05 \times V \times 200}{W}$$

where:

0.05 = molarity of NaOH or HCl used for titration

v = ml NaOH or HCl used for titration

w = weight of air – dried soil sample in grams

3.5.1.6 Calculation of effective cation exchange capacity

Effective cation exchange capacity (ECEC) was calculated by the sum of exchangeable bases (Ca, Mg, K, and Na) and exchangeable acidity (Al and H).

3.5.1.7 Percent base saturation

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

3.5.2 Soil physical analysis

3.5.2.1 Particle size distribution

Soil particle size distribution analysis was determined by the Hydrometer method as per Anderson and Ingram (1998). Fifty one grams (51.0 g) of soil was shaken with 100 ml distilled water and 50 ml of 5 % dispersing agent (5 % sodium hexametaphosphate) in a corked 500 ml plastic bottle at 300 rpm for 2 hours, then transferred to 1.0 L sedimentation cylinder and made up to the 1 litre mark with distilled water. The soil suspension was plunged and stirred vigorously after which a hydrometer and thermometer were used to measure the density and temperature, respectively of the suspension of soil and water at 40 seconds. The soil suspension was allowed to stand undisturbed for 3 hours after which the second hydrometer and thermometer readings were taken (Okalebo *et al.*, 1993).

Calculation:

$$\% \text{ Sand} = 100 – (H_1 + 0.2 \times (T_1 – 20.0) – 2.0) \times 2$$

$$\% \text{ Clay} = (H_2 + 0.2 \times (T_2 - 20) – 20.0) \times 2$$

% Silt = 100 – (% Sand + % Clay)

where:

H_1 = first hydrometer reading at 40 seconds
H_2 = second hydrometer reading at 3 hours

T_1 = temperature of suspension at first hydrometer reading at 40 seconds

T_2 = temperature of suspension at second hydrometer reading at 3hours.

$0.2(T_1-20)$ = temperature correction factor to be added to the hydrometer reading

-2.0 = Salt correction factor to be added to the hydrometer reading

3.5.2.2 Determination of soil bulk density

A core sampler of 10 cm length, 9.8 cm diameter (r = 4.9 cm) and 69 g weight (W_1) was used to take soil samples from each plot at ten (10) days interval during the crop growing period as described by Anderson and Ingram (1998). Before inserting the tube within the soil, 1 - 2 cm of surface soil was removed and a knife was used to remove the soil from the tube ends. The samples were weighed fresh (W_2) and oven dried at 105 ^oC for two days. Bulk density was calculated using the formula:

$$\text{Bulk density}(\rho_b)\ (g\ cm^{-3}) = \frac{W_3}{V}$$

where:

W_3 = dry sample weight (g)

V = volume of core sampler ($V = \pi r^2 h = 753.914\ cm^3$)

3.5.2.3 Determination of gravimetric moisture content

This was determined using the gravimetric method Marshall and Holmes (1988). The method is based on removing soil moisture by oven-drying a soil sample until the weight remains constant. The moisture content (%) is calculated from the sample weight before and after drying:

$$\text{Moisture content (\%)} = \frac{(W_2 - W_1) - W_3}{W_3} \times 100$$

where:

W_1 = Weight of the core sampler (g)

W_2 = Weight of moist soil + the core sampler (g)

W_3 = Weight of dried soil

3.5.2.4 Volumetric water content

The volumetric water (θ_V) content was calculated by multiplying the moisture content by the ratio of soil bulk density over water density.

$$\theta_V (m^3 m^{-3}) = \theta_m \times \frac{\rho_b}{\theta_w}$$

where:

ρ_w = density of water ($\theta_w = 1000 \text{ kg m}^{-3}$)

ρ_b = bulk density (kg m^{-3})

θ_m= moisture content

3.6 Laboratory analysis of cattle manure, compost, pearl millet and cowpea grain, straw and haulm

The raw materials used for composting were cattle manure and cowpea haulm which were analyzed for their nutrient content (total N, P, K, Ca and Mg, organic carbon, polyphenol and lignin content). Also millet and cowpea grain, straw and haulm samples were also taken at the end of each cropping season and analyzed for their chemical parameters (total N, P and K).

3.6.1 Determination of total nitrogen

One gram (1 g) of the compost or plant material was weighed into a Kjeldahl flask, Selenium catalyst was added and 20 ml of concentrated H_2SO_4 were also added to the mixture. The digestion flask with the mixture was heated in the DK20 heating digester block starting at a temperature of 80 ^oC and then the temperature raised to 350 ^oC. The content of the digestion flasks were heated until the volume was reduced to 3 - 4 ml. The content of the digestion flask was cooled and the volume made up to 100 ml in a volumetric flasks. Ten (10) milliliters of each sample digest was transferred by means of pipette into a Kjeldahl distillation apparatus. To this, 20 ml of 40 % NaOH was added and distilled (Okalebo *et al.*, 1993). Distillate was collected over 10 ml of 4 % boric acid and three drops of mixed indicator in a 250 ml conical flask for 5 minutes. The presence of nitrogen gave a light blue colour. Two hundred millilitrers (200 ml) of the distillate was titrated with 0.1 N HCl till the colour changed from light blue to gray and suddenly flashed to pink. A blank was carried out with the solution sample. The weight of N was calculated as; 14 g of N contained in one mili-equivalent weight of NH_3.The percentage of nitrogen in the sample was calculated as:

$$\% \text{ Total N} = \frac{14 \times A - B \times \text{concentration of acid}}{1000 \times 1} \times 100$$

where:

A = volume of standard HCl used in the sample titration

B = volume of standard HCl used in the blank titration

14 = atomic weight of nitrogen

1 = mass of the sample in gram

3.6.2 Determination of total phosphorus, potassium, calcium and magnesium

A 1.0 g of the milled compost or plant was ashed in a muffle furnace at 550 ^{o}C for 4 hours after which the ash was dissolved in 2.0 *M* HCl solution, heated and filtered. The filtrate was diluted to 100 ml with distilled water.

3.6.2.1 Determination of total phosphorus

A 5 ml aliquot of the supernatant digest was pipetted into a 50 ml volumetric flask. Five (5.0) millilitres of ammonium molybdate - ammonium vanadate solution was added. Volume of mixture was made up with distilled water to the 50 ml mark and allowed to stand undisturbed for 30 minutes for colour development. A standard curve was developed concurrently with P concentrations ranging from 0.0, 0.8, 1.6, 2.4, 3.2 and 4.0 µg/ml. The absorbance of blank, control and the samples were read on the Jenway 6051 Colorimeter at a wavelength of 430 nm.

A standard curve was obtained by plotting the absorbance values of the standard solutions against their respective concentrations. Phosphorus concentration of the samples was determined from the standard curve.

Calculation:

$$\% \text{P} = \frac{\text{Graph reading x 50}}{\text{x 1000}}\ \text{w}$$

where:

w = weight of sample

50 = final volume of solution

3.6.2.2 Determination of total potassium

Potassium in the ash solution was determined using a flame photometer. Potassium standard solutions were prepared with the following concentrations: 0, 2, 4, 6, 8 and 10 μg/ml. The emission values were read on the flame photometer. A standard curve was obtained by plotting emission values against their respective concentrations.

Calculation:

$$\% \text{K} = \frac{\text{Graph reading}}{\text{x 100}}\ \text{w}$$

where:

w = weight of sample

3.6.2.3 Determination of total calcium and magnesium

A 10 ml aliquot of ash solution was put in an erlenmeyer flask. Ten milliliters of 10 % potassium hydroxide, 1 ml of triethanolamine and few drops of potassium cyanide solutions were added. The mixture was titrated with 0.02 *M* EDTA solution with cal red as an indicator.

3.6.2.4 Determination of total calcium

Ten millilitres of the ash solution was put in an erlenmeyer flask. Potassium hydroxide, buffer solution, 1 ml of triethanolamine and few drops of potassium cyanide solutions were added. The mixture was titrated with 0.02 *M* EDTA solution with murexide as an indicator.

Calculation:

$$\% \text{ Ca} = \frac{\text{V x 0.02 x 20}}{\text{W}}$$

where:

V = ml of EDTA required for titration

0.02 = molarity of EDTA

20 = equivalent weight of Ca (40/2)

W = weight of sample

3.6.2.5 Determination of total magnesium

The concentration of magnesium in the residue was calculated by subtracting the value obtained from calcium alone from the calcium + magnesium value.

Calculation:

$$\% \text{ Mg} = \frac{\text{V x 0.02 x 12}}{\text{W}}$$

where:

V = ml of EDTA required for titration

0.02 = molarity of EDTA

12 = equivalent weight of Mg (24/2)

w = weight of sample

3.6.3 Determination of organic carbon

Organic carbon content was determined using the wet dichromate oxidation method. A 0.05 g of organic material (manure, compost and cowpea haulm) was weighed into an erlenmeyer flask. Ten millilitres concentrated sulphuric acid, 10 ml 0.1667 *M* $K_2Cr_2O_7$, and 10 ml of orthophosphoric acid were added. After the addition of 200 ml of distilled water, the solution was allowed to stand for 30 minutes on an asbestos sheet and back titrated with 0.333 *M* $FeSO_4$ solutions with diphenylamine indicator Anderson and

Ingram (1998).

Calculation:

$$\% \text{ Organic C} = \frac{(\text{m.e.}K_2Cr_2O_7 - \text{m.e.}FeSO_4) \times 1.32 \times 0.003}{W} \times 100$$

where:

m.e. = molarity of solution x ml of solution used

w = weight of oven dried sample in grams

0.003 = milli–equivalent weight of carbon in grams (12/4000)

1.32 = correction factor

3.6.4 Determination of polyphenol content

This was determined using the Folin - Denis method (Anderson and Ingram, 1998). A 1 g each of oven dried and milled manure, compost or cowpea haulm were weighed into a 50 ml beaker. Twenty millilitres of 50 % methanol was added, covered and placed in a water bath at 80 ^{o}C for 1 hour. The extract was filtered through Whatnan No. 42 filter paper into a 50 ml volumetric flask using 50 % aqueous methanol to rinse, and made up to the mark with distilled water. Standard solutions of tannic acid (0, 1, 2 and 4 ml) were prepared. The samples and tannic acid standards were subjected to colour development using Folin - Denis reagent. Values of absorbance of the standard and sample solutions were read on a spectronic 21 D spectrophotometer at 760 nm wavelength. A standard curve was obtained by plotting absorbance values against concentrations of the standard solutions, and used to determine the concentration of the sample solutions Anderson and Ingram (1998).

Calculation:

$$\text{Total extractable polyphenol (\%)} = \frac{\text{Graph reading x 50 x 100}}{\text{W x 1000}}$$

where:

W = weight of sample in grams

3.6.5 Determination of lignin content

Lignin is an aromatic compound composed of repeating benzene rings that are branched and complex (Franzluebbers *et al.*, 1996). It is defined as the residual organic fraction after chemical extraction which is resistant to microbial degradation. The acid detergent fibre method was used in determining the lignin content of the residues (Anderson and Ingram, 1998). Two grams of milled residue was weighed into a sealed pyrex tube. To this, 25 ml of 0.05 *M* sulphuric acid was added, heated at 100 ^{o}C for 1 hour, cooled and centrifuged. The supernatant solution was saved in another container. This was repeated with distilled water to remove most of the sulphuric acid in the residue. The solution was transferred into a 100 ml Erlenmeyer flask with 40 ml distilled water, boiled for 3 hours and filtered. The residue was washed with water, dried at 60 ^{o}C for 48 hours, weighed and ashed in a muffle furnace at 550 ^{o}C for 4 hours. The loss in weight on ignition is the lignin content of residue (Anderson and Ingram, 1998).

3.7 Treatments used and experimental design

A 3 x 4 factorial experiment arranged in randomized complete block design (RCBD) with three replications was used. Each plot measured 10.5 m x 6 m. The space between plots was 2 m and the field had a total area of 3,139 m^2 (73 m long and 43 m wide). Pearl millet was sown first followed by cowpea one week later. Pearl millet and cowpea were sown 5 July and 14 July 2013 and 13 July and 19 July 2014 respectively. Two types of amendments were used during this experiment; mineral fertilizer (NPK for pearl millet and DAP for cowpea) and compost. Compost (C) with three rates (0, 2500 and 5000 kg ha^{-1}) and mineral fertilizers (MF) with four rates (0, 100, 175 and 200 kg ha^{-1} for NPK and 0, 50, 75 and 100 kg ha^{-1} for DAP) corresponding to 0, 50, 75 and 100 % of the recommended rate which is 200 kg $ha^{-1}$for NPK (15-15-15) and 100 kg $ha^{-1}$for DAP (18-46-0) (Buerkert *et al.*, 2001b). NPK was applied to pearl millet while DAP to cowpea. Compost was broadcast one week before sowing and mineral fertilizer was spot applied (incorporated) twice. The experiment was repeated on the same plots in 2014.

The combination of the two factors gave 12 treatments outlined below:

T_1 (control) = 0C+0NPK/DAP ; T_2 = 100NPK/50DAP ; T_3 = 175NPK/75DAP

T_4 = 200NPK/100DAP ; T_5 = 2500 C ; T_6 = 2500 C + 100NPK/50DAP ; T_7 = 2500 C + 175NPK/75DAP ; T_8 = 2500 C + 200NPK/100DAP ; T_9 = 5000 C ; T_{10} = 5000 C + 100NPK/50DAP ; T_{11} = 5000 C + 175NPK/75DAP ; T_{12} = 5000 C + 175NPK/75DAP

3.8 Data collection

3.8.1 Plant height

Pearl millet height was recorded each week using a rule graduated from 0 - 3 m. Five pearl millet hills per plot were marked in which one plant per hill was measured weekly.

3.8.2 Leaf area index

Leaves of two plants were randomly harvested from each plot, counted and then average was worked out. Length and width of the top, middle and bottom leaves of each plant were measured and used to calculate leaf area. The formula below was used for the calculation leaf area index (LAI) (Amanullah *et al.*, 2007).

$$\text{Leaf area Index (LAI)} = (\text{length x width}) \text{ x } 0.75$$

3.8.3 Crop growth rate

Three hills of pearl millet were marked per plot within which one plant per hill was uprooted and the fresh and dried weight recorded. For cowpea, two hills per plot were uprooted for the determination of crop growth rate (CGR). All millet and cowpea samples were oven dried at 65 ^oC for two days. To obtain the CGR, the formula below was used

$$\text{CGR } (g/m^2/day) = \frac{\text{fresh weight - dried weight}}{t}$$

where:

t = time in days

3.8.4 Pearl millet and cowpea grain and dry matter yield

A total area of 24 m^2 and 12 m^2 per plot respectively for pearl millet and cowpea were harvested for grain and dry matter yield and then extrapolated to obtain yield per hectare. Pearl millet straw and cowpea haulm were sun-dried and weighed.

3.8.5 Pearl millet and cowpea harvest index

Pearl millet and cowpea havest index (HI) which is the ratio of economic yield to biological yield, was calculated using the formula below:

$$HI\ (\%) = \frac{\text{Grain yield}}{\text{Biomass yield}} \times 100$$

3.8.6 Nitrogen and phosphorus use efficiency and recovery in grain and straw/haulm

Pearl millet and cowpea nitrogen and phosphorus use efficiency and recovery were calculated using the following formula (Snyder and Bruulsema, 2007):

$$N/P\ \text{use efficiency} = \frac{Y_{treat}}{\text{Grain N/P}_{\text{treat uptake}}}$$

where:

Y_{treat} = Grain yield of the treatment

$$N/P\%\ \text{recovery} = \frac{(\text{Total N/P millet/cowpea})_f - (\text{Total N/P millet/cowpea})_C}{\text{Amount of N/P added}} \times 100$$

where:

f = fertilized plot

C = control plot

3.9 Evaluation of the sustainability yield index and the agronomic efficiency of compost and mineral fertilizer under strip cropping

The sustainability yield index (SYI) and agronomic efficiency (AE) were calculated using the following formula described by Efthimiadou *et al.* (2010).

$$SYI = \frac{Ym - SdY - Y^{0}}{YmaxF} \quad \text{and} \quad AE = \_\_\_\_$$

where:

Ym = mean yield
Sd = standard deviation

Ymax = maximum yield obtained under a set of management practice

Y = grain yield of fertilized plot

Yo = grain yield in control plot

F = amount of amendment applied.

3.10 Economic evaluation of combined use of compost and mineral fertilizer

The economic analysis in this study was done using the local market prices of the various inputs (mineral fertilizer NPK and DAP). However, manure was collected freely within the station. All costs from transporting manure and purchasing of cowpea haulm were summed. The cost of 1 kg (1 kg = 65 FCFA) of compost was found by dividing the total cost involved in the whole composting process by the total quantity of compost produced. The cost of land preparation, incorporation of amendments (compost and mineral fertilizer), sowing, tillage and harvesting did not differ among treatments and were not taken into account during the economic evaluation (Mucheru-Muna *et al.*, 2007) and (Opoku, 2011). Economic analysis was done using the formula developed by Khaliq *et al.* (2006).

Net return = value of grain yield obtained-cost of mineral/organic nutrient sources

$$\text{Value Cost Ratio (VCR)} = \frac{\text{Value of grain yield obtained}}{\text{Cost of mineral or organic resources}}$$

$$\text{Relative Increase in Income (RII)} = \frac{\text{Net income}}{\text{Income at control}} \times 100$$

Also added benefit resulted from integrated use of compost and mineral fertilizer was calculated using the following formula (Vanlauwe *et al.*, 2002):

$$AB = Y_{comb} - (Y_{fert} - Y_{con}) - (Y_{comp} - Y_{con}) - Y_{con}$$

where:

AB = added benefit

Y_{comb} = mean grain yield of treatment receiving both compost and fertilizer

Y_{fert} = mean grain yield of treatment receiving fertilizer

Y_{comp}= mean grain yield of treatment receiving compost Y_{con}

= mean grain yield of control.

3.11 Evaluation of nitrogen and phosphorus partial balance of combined application of composted cattle manure and mineral fertilizer

Partial balance was calculated after application of combined composted cattle manure and mineral fertilizer taking into account only easily measurable nutrient flows. This refers to inputs of nutrients in the form of mineral fertilizers (IN1) and composted cattle manure (IN2) and outputs in harvested product (OUT1); crop residues (OUT2) using the formula developed by (Roy *et al.*, 2003):

$$(IN_1 + IN_2) - (OUT_1 + OUT_2)$$

3.12 Data analysis

All statistical analysis was performed using GenStat 9th edition statistical package (2007 edition). Data on treatments and times of sampling of decomposing compost, nutrient release pattern, changes in soil chemical and physical properties and pearl millet and cowpea growth parameters, grain and biomass yield were subjected to two - way analysis of variance (ANOVA) at the probability of 5 %. Repeated measurements analysis was also performed for millet height. Polynomial contrast analysis and mean separation was performed using the Duncan‟s least significant difference (LSD) method at 5 %. Correlation analysis between some of the parameters estimated was done.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Rainfall pattern during the cropping periods

4.1.1 Results

The total rainfall amounts recorded during the cropping seasons were 621 mm in 2013 and 374 mm in 2014. Figure 4.1 shows the distribution of the rainfall over the 2013 cropping season with higher values recorded daily between 27 to 51 days after sowing (DAS). During the year 2014, less than 10 mm of the daily rainfall was received after 51 DAS which lasted till the end of the cropping season.

4.1.2 Discussion

Rainfall supply is one of the most critical factors limiting crop growth and yield. Thus, according to Mason *et al.* (2014), limited and erratic rainfall, short and variable growing season are all obstacles to pearl millet production. The results during both cropping seasons showed that rainfall was within the long-term rainfall range recorded for the experimental site (350 - 650 mm per year). The total amount of rainfall recorded during 2014 was slightly above the minimum rainfall reported for the long-term period, while in 2013 it was almost equal to the highest value for the long-term period. This low rainfall pattern observed in 2014 around crop maturity (ie. 70 to 90 days after sowing for millet) may have had an impact on crop productivity, because under water stress most of flowers abort resulting in low crop yield.

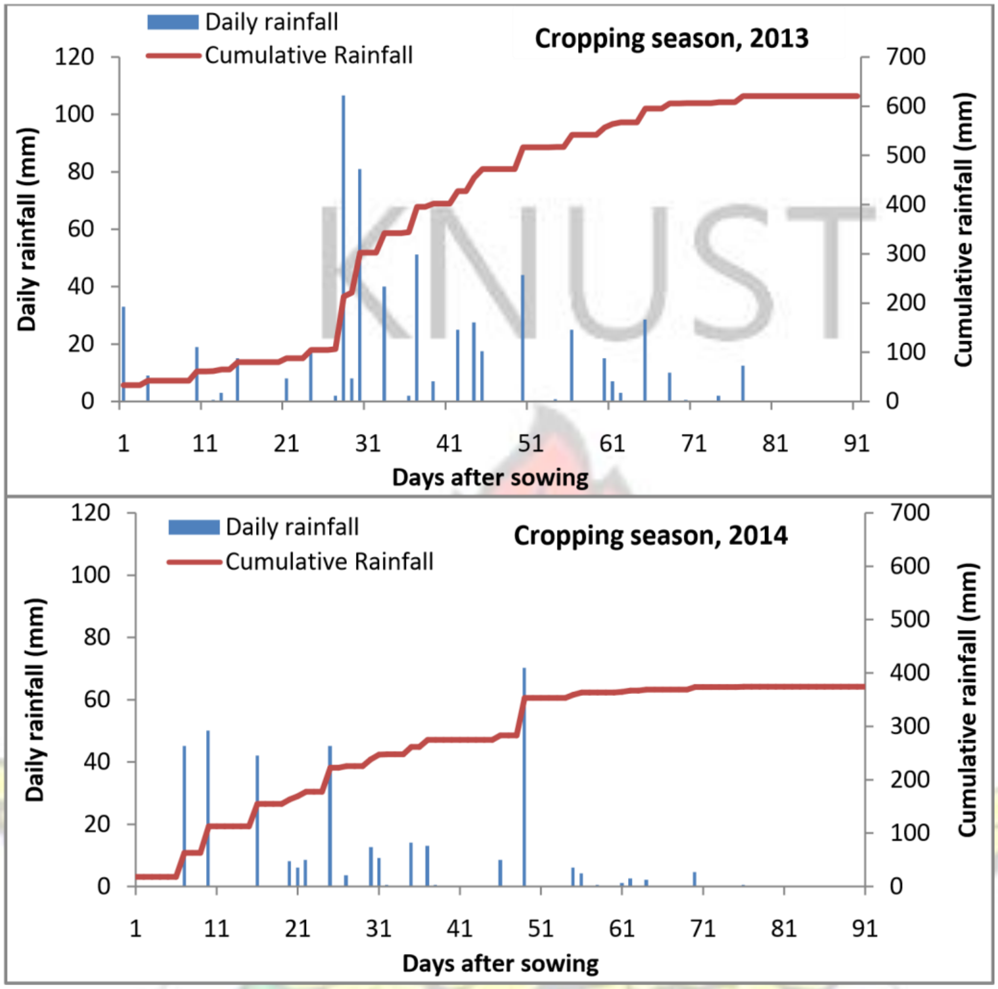

Figure 4.1: Rainfall distribution during 2013 and 2014 cropping seasons

4.2 Initial soil physico-chemical properties of the experimental site

4.2.1 Results

The initial soil physico-chemical properties of the sandy arenosol of the study area are presented in Table 4.1. The results indicated that the soil was strongly acid (pH = 5.3) with low organic carbon (0.11 %), total nitrogen (0.01%) and available phosphorus (8.72 mg kg^{-1}) contents. Initial soil exchangeable bases of the experimental site recorded were 0.68, 0.07, 0.49 and 0.26 $cmol_+ kg^{-1}$ of Ca, Mg, K and Na respectively. Concentrations of the acidic cations were 0.39 and 0.31 cmol$_+$ kg^{-1} for Al^{3+} and H^+ respectively. The effective cation exchange capacity (ECEC) was 2.2 cmol$_+$ kg^{-1} whilst percent base saturation was 68.18 % .

Soil particle size analysis showed that the soil contained 93.20 % sand, 3.90 % silt and 2.88 % clay described as sand texture (Table 4.1). This textural characteristic correspond to the properties of an arenosol and confirms the fact that the soil of the study area is an arenosol.

Table 4.1: Initial soil physico-chemical properties of the experimental site*

Soil parameters	**Mean (0 - 20 cm)**
pH (1:1 Soil : water)	5.30 ± 0.14
Organic carbon (%)	0.11 ± 0.02
Total N (%)	0.01 ± 0.00
Available P (mg/kg)	8.72 ± 0.57
Exchangeable cations (cmol$_+$ kg^{-1} of soil)	
Ca	0.68 ± 0.08
Mg	0.07 ± 0.02
K	0.49 ± 0.16
Na	0.26 ± 0.05
Al	0.39 ± 0.06
H	0.31 ± 0.03
ECEC	2.20 ± 0.4
Base saturation (%)	68.18 ± 0.78
Physical parameters	
Sand (%)	93.2 ± 029
Silt (%)	3.90 ± 0.1
Clay (%)	2.88 ± 0.29
Texture	Sand

*Values are means of triplicate sample analysis; □ standard error

4.2.2 Discussion

The initial pH value (5.3) of the experimental site was similar to the findings of Akponikpe *et al.* (2008) who found a pH of 5.4 at Sadoré in Niger. With acidic pH, plants cannot easily absorb natural or applied nutrients particularly phosphorus and it delays microbial activity in the soil (Haile *et al.*, 2009). All this leads to low crop yields. The low pH in the study area could be attributed to low Ca and Mg contents of the soil. According to Whalen *et al.* (2000), most agricultural crops produce well in the pH range of 5.6 to 7.5 in sandy soils.

Soil organic carbon (SOC) value (0.11 %) of the experimental site was similar to the findings of Fatondji *et al.* (2009) who reported organic carbon content of 0.10 % in soils of Sadoré, Niger. Also, Akponikpe *et al.* (2008) found low organic carbon content (0.18 %) at Sadoré in south-western Niger. Bationo *et al.* (2006b) indicated that SOC is crucial in determining response to N and P fertilization. Landon (2014) rated soil containing organic carbon > 20 % as very high, 10 – 20 % high, 4 – 10 % medium, 2 – 4 % low and < 2 % very low. With reference to these ranges, the percent organic carbon of the study area was very low. This could be explained by the lack of addition of organic resources such as farm yard manure and compost. Soil organic carbon is an index of sustainable land management (Nandwa, 2001).

The initial total nitrogen content (0.01 %) was very low. Landon (2014) rated percent total N content in soil > 1.0 as very high, 0.5 – 1.0 high, 0.2 – 0.5 medium, 0.1 – 0.2 low and < 0.1 very low. With reference to these ranges, the total N content of the study area was very low due to the low organic matter content since nitrogen is an essential component of organic matter.

The initial available P content of the study area is low but around the value of 8 mg kg^{-1} which according to Manu *et al.* (1991) has been determined to be the critical P level required to obtain 90 % of the maximum millet yield in sandy soils of Niger. Buchholz *et al.* (2004) provided available P ranges as: < 3 mg kg^{-1}-very low, < 10 mg kg^{-1}-low, between 10 - 20 mg kg^{-1}-medium, > 20 mg kg^{-1}-high.

According to the rating reported by Metson (1961), Ca and Mg of the study area can be classified as very low, K as moderate and Na as low. Robertson *et al.* (1999) showed that in highly weathered sandy soil where pH is low and with low organic matter, exchangeable bases content and availability can be affected. Acid sandy soils that have very low levels of exchangeable calcium and magnesium may limit plant growth.

The effective cation exchange capacity (ECEC) (2.2 $cmol_+$ kg^{-1} of soil) of the study area was very low and could be explained by the low pH and soil organic matter content. Arthur (2009) reported that low ECEC value could be due to low pH (5.07). According to the rating given by Landon (2014), ECEC value (i.e. in $cmol_+$ kg^{-1}) > 40 is very high, 25 – 40 is high, 15 – 25 is medium, 5 – 15 is low and < 5 is very low.

The initial percent base saturation of 68.18 % corresponds to the high level as classified by Metson (1961). Percent base saturation provides an indication of how closely nutrient status approaches potential fertility.

4.3 Soil physico-chemical properties after sole and combined application of compost and mineral fertilizer

4.3.1 Results

4.3.1.1 Soil pH

Sole application of composted cattle manure and mineral fertilizer and their combination did not significantly ($P > 0.05$) change the soil pH of the experimental site even though an increase from the initial pH was observed in all treatments during the 2013 and 2014 cropping seasons (Table 4.2). The pH values in 2014 were higher than the 2013 values under all treatments as shown in Table 4.2 and Appendix 1. The highest pH value of 5.63 was recorded under 2500 kg ha^{-1} compost + 200 kg ha^{-1} NPK in 2013 while 6.26 resulted from the sole application of 2500 kg ha^{-1} compost during the 2014 cropping season.

4.3.1.2 Soil organic carbon

Changes in soil organic carbon content (SOC) following the application of the different amendments are presented in Table 4.2. An increase in organic carbon content relative to the initial SOC content (0.11 %) was observed in all treatments except the control in 2013 even though these changes were not significant among treatments. In 2014 cropping season, organic carbon content decreased in most treatments compared to the initial value (0.11 %). The highest organic carbon content of 0.28 % was recorded under the application of 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK in 2013 while 0.13 was recorded in 2014 under the sole applications of 2500 and 5000 kg ha^{-1} compost.

Table 4.2: Effect of compost, mineral fertilizer and their combinations on soil pH and

soil organic carbon during the 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})			pH(1:1 H_2O)				Organic carbon (%)		
Compost	NPK fertilizer		2013		2014		2013		2014
0 0	5.51	5.95	0.11	0.12	100		5.39	5.65	0.24
									0.09
	175		5.57		6.01		0.22		0.10
	200		5.50		6.23		0.25		0.09
2500	0	5.42	6.26	0.19	0.13	100		5.46	5.42
								0.25	0.08
	175		5.47		5.65		0.25		0.07
	200		5.63		6.22		0.22		0.11
5000	0	5.51	5.69	0.25	0.13	100		5.36	5.70
								0.21	0.10
	175		5.44		5.86		0.28		0.07
	200		5.33		5.97		0.24		0.11
CV (%)			3.70		7.30		60.20		41.40
Lsd (0.05)									
Lsd C			0.17		0.37		0.07		0.03
Lsd NPK			0.19		0.42		0.08		0.04
Lsd C x NPK			0.37		0.74		0.14		0.07

C = compost

4.3.1.3 Soil total N

Soil total nitrogen content after sole and combined applications of compost and mineral fertilizer is presented in Table 4.3. The total soil nitrogen content doubled after amendment application in all treatments compared to the initial soil nitrogen content (0.01 %) during 2013 cropping season but was however, still low. In 2014 cropping season, this increase was noticed in most treatments (e.g. 2500 kg ha^{-1} + 175 kg ha^{-1} NPKfertilizer).

Table 4.3: Effect of compost, mineral fertilizer and their combinations on soil total N

and available P during the 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})		Total N (%)		Available P (mg kg^{-1})	
Compost	NPK fertilizer	2013	2014	2013	2014
0	0	0.02	0.01	7.04	7.04
	100	0.02	0.02	8.58	10.61
	175	0.02	0.02	9.16	10.88
	200	0.02	0.02	8.32	13.40
2500	0	0.02	0.02	6.75	16.36
	100	0.02	0.01	9.71	12.09
	175	0.02	0.02	8.33	10.61
	200	0.02	0.01	9.11	14.39
5000	0	0.02	0.01	7.01	11.43
	100	0.02	0.02	6.48	12.01
	175	0.02	0.02	6.52	10.34
	200	0.02	0.01	8.58	14.89
CV (%)		12.40	39.30	24.80	25.90
Lsd (0.05)					
Lsd C		0.002	0.005	1.670	2.780
Lsd NPK		0.002	0.006	1.929	3.210
Lsd C x NPK		0.004	0.011	3.341	5.570

C = compost

4.3.1.4 Soil available P

Table 4.3 presents the changes in available phosphorus after sole and integrated application of compost and mineral fertilizer. In comparison to the initial available P value of 8.72 mg kg^{-1}, an increase was observed in all treatments in 2014 except the control. The highest available P values of 9.710 in 2013 and 16.360 mg kg^{-1} in 2014 were obtained by applying 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK and 2500 kg ha^{-1} compost, respectively (Table 4.3). The increase in available phosphorus values obtained among treatments was not significant during both cropping seasons. In both years, the control had the same P value of 7.04 mg kg^{-1}, which was lower than the initial available phosphorus value (8.72 mg kg^{-1}) (Table 4.3).

4.3.1.5 Exchangeable bases

Sole and combined applications of compost and mineral fertilizer led to changes in soil exchangeable bases content as presented in Tables 4.4 and 4.5. Under all treatments, Ca content was higher in 2014 relative to 2013 and also higher than the initial Ca content of 0.68 cmol$_+$ kg^{-1}. The year significantly affected the exchangeable bases (Appendix 1). Higher Ca contents of 0.90 and 1.06 cmol$_+$ kg^{-1} were obtained by applying 200 kg ha^{-1} NPK in 2013 and 2500 kg ha^{-1} compost respectively in 2014. On the other hand, higher values of soil magnesium content were recorded under all treatments in both cropping years compared to an initial value of 0.07 cmol$_+$ kg^{-1} (Table 4.4). Furthermore, all treatments in 2014 had higher Mg content than in 2013 even though there were no significant differences among treatments. The highest Mg contents of 0.33 and 0.74 cmol$_+$ kg^{-1} were obtained when 200 kg ha^{-1} NKP was applied in 2013 and 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK in 2014 respectively.

Table 4.4: Effect of compost, mineral fertilizer and their combinations on soil exchangeable calcium and magnesium during the 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})		Ca (cmol$_+$ kg^{-1})		Mg (cmol$_+$ kg^{-1})	
Compost	NPK fertilizer	2013	2014	2013	2014
0	0	0.75	0.85	0.17	0.49
	100	0.72	0.88	0.24	0.57
	175	0.62	1.05	0.06	0.41
	200	0.90	0.88	0.33	0.49

2500	0	0.57	0.91	0.09	0.61 100	0.63	0.81
						0.13	0.74
	175		0.89	0.77		0.32	0.71
	200		0.55	1.03		0.04	0.35
5000	0	0.65	1.06	0.09	0.36 100	0.62	1.01
						0.08	0.42
	175		0.60	0.83		0.16	0.63
			0.53	0.98		0.09	0.37 200
			38.20	15.90		86.10	42.30 CV (%)
Lsd (0.05)							
Lsd C			0.22	0.12		0.11	0.18
Lsd NPK 0.25	0.14	0.12	0.21 Lsd C x NPK			0.43	0.25
0.22	0.37						

C = compost

Table 4.5 presents changes in potassium and sodium after sole and combined application of compost and mineral fertilizer. All treatments had higher potassium contents than the initial value of 0.49 cmol₊ kg^{-1} during the two cropping seasons. Moreover, all treatments recorded relatively higher potassium content in 2013 than in 2014 cropping season. On the other hand, apart from 200 kg ha^{-1} NPK, 2500 kg ha^{-1} compost + 200 kg ha^{-1} NPK and 5000 kg ha^{-1} compost + 200 kg ha^{-1} NPK, all other treatments had higher sodium content in 2013 than the initial value of 0.26 cmol$_+$ kg^{-1}. Similar trend of Na content was also observed in 2014. The highest Na content of 0.36 cmol$_+$ kg^{-1} was obtained under the application of 100 and 175 kg ha^{-1} NPK during the 2013 cropping season.

Table 4.5: Effect of compost, mineral fertilizer and their combinations on soil exchangeable potassium and sodium during the 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})	K (cmol$_+$ kg^{-1})	Na (cmol$_+$ kg^{-1})

Compost	NPK fertilizer		2013	2014	2013	2014	
0	0	1.24	0.97	0.35	0.07 100	1.31	
	0.98	0.36	0.07				
	175		1.40	0.95	0.36	0.07	
	200		1.51	0.95	0.24	0.07	
2500	0	1.39	1.03	0.27	0.07 100	1.77	
	0.92	0.43	0.07				
	175		1.21	0.97	0.28	0.06	
	200		1.24	0.96	0.23	0.07	
5000	0	1.31	0.86	0.33	0.07 100	1.50	
	1.16	0.34	0.07				
	175		1.75	0.86	0.35	0.06	
			0.52	0.85	0.25	0.06	200
			47.70	20.50	31.30	19.50	CV (%)
Lsd (0.05)							
Lsd C			0.54	0.7	0.08	0.01	
Lsd NPK 0.63	0.19	0.09	0.01 Lsd C x NPK			1.09	
0.33	1.17	0.02					

C = compost

4.3.1.6 Exchangeable acidity

Changes in aluminium (Al^{3+}) and hydrogen (H^+) concentrations were observed after the application of treatments (Table 4.6). Apart from the application of 175 kg ha^{-1} NPK, 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 5000 kg ha^{-1} compost + 200 kg ha^{-1} NPK, all other treatments recorded higher values of Al^{3+} in 2013 compared to the initial value of 0.39 cmol$_+$ kg^{-1}. On the other hand, higher values of H^+ were recorded under all treatments in 2013 except for the application of 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK compared to the initial concentration of 0.31 cmol$_+$ kg^{-1}.

Table 4.6: Effect of compost, mineral fertilizer and their combination on soil exchangeable acidity during the 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})			Al (cmol$_+$ kg^{-1})		H (cmol$_+$ kg^{-1})		
Compost	NPK fertilizer		2013	2014	2013	2014	
0	0	0.45	0.45	0.45	0.39 100	0.45	
	0.33	0.45	0.28				
	175		0.33	0.33	0.39	0.33	
	200		0.50	0.39	0.45	0.28	
2500	0	0.45	0.33	0.33	0.22 100	0.50	
	0.50	0.45	0.33				
	175		0.33	0.39	0.39	0.33	
	200		0.56	0.39	0.50	0.33	
5000	0	0.50	0.28	0.45	0.28 100	0.50	
	0.33	0.33	0.28				
	175		0.56	0.39	0.22	0.39	
			0.39	0.33	0.33	0.33	200
			26.70	22.70	41.00	24.20	CV (%)
Lsd (0.05)							
Lsd C			0.10	0.07	0.14	0.06	
Lsd NPK			0.12	0.08	0.16	0.07	
Lsd C x NPK			0.21	0.14	0.27	0.13	

C = compost

4.3.1.7 Effective cation exchange capacity and percent base saturation

The effective cation exchange capacity (ECEC) of the soil during the 2013 and 2014 cropping seasons ranged from 2.10 - 3.92 cmol$_+$ kg^{-1} and 2.90 - 3.37 cmol$_+$ kg^{-1} respectively as shown in Table 4.7. All treatments recorded higher ECEC values compared to the initial 2.2 cmol$_+$ kg^{-1} value during both cropping seasons except the application of 5000 kg ha^{-1} compost + 200 kg ha^{-1} NPK.

On the other hand, base saturation in 2013 and 2014 fluctuated between 65.72 - 78.80 % and 74.03 - 82.44 %, respectively (Table 4.7). Application of 5000 kg ha^{-1} compost + 200 kg ha^{-1} NPK had a lower base saturation compared to the initial value of 68.18 % in both cropping seasons. The 2014 cropping season obtained higher base saturation values (80.35, 82.44 and 81.22 %) compared to the 2013 cropping season.

Table 4.7: Effect of compost, mineral fertilizer and their combinations on ECEC and base saturation during the 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})		ECEC (cmol$_+$ kg^{-1})		Base saturation (%)	
Compost	NPK fertilizer	2013	2014	2013	2014
0	0	3.40	3.22	73.80	74.03
	100	3.52	3.11	74.74	80.35
	175	3.16	3.15	77.10	78.77
	200	3.92	3.06	75.88	78.14
2500	0	3.10	3.17	74.85	82.44
	100	3.90	3.37	75.71	75.24
	175	3.42	3.23	78.86	77.56
	200	3.11	3.13	65.99	76.87
5000	0	3.33	2.90	71.59	80.84
	100	3.37	3.28	75.25	81.32
	175	3.64	3.16	78.57	75.32
	200	2.93	2.11	75.02	77.17
CV (%)		145.10	271.00	65.72	67.68
Lsd (0.05)					
Lsd C		1.19	1.14	0.80	0.89
Lsd NPK		1.37	0.70	0.80	0.79
Lsd C x NPK		3.39	1.24	0.86	0.78

C = compost

4.3.1.8 Soil physical properties after sole and combined application of compost and mineral fertilizer

Changes in soil moisture content, volumetric water content and soil bulk density were observed after the sole and combined applications of compost and mineral fertilizer during the two cropping seasons (Table 4.8). Contrary to expectation, the highest bulk density values of 1.75 (2013) and 1.68 g cm^{-3} (2014) were recorded under the application of 5000 kg ha^{-1} compost + 100 kg ha^{-1} NPK and 5000 kg ha^{-1} compost + 200 kg ha^{-1} (Table 4.8). Moisture content was relatively higher in 2013 than in 2014 in all treatments. Similar trend was observed for volumetric water content. The highest volumetric water content value of 12.31 m^{3}m^{-3} was recorded by applying 5000 kg ha^{-1} compost + 100 kg ha^{-1} NPK and 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK during the 2013 cropping season.

Table 4.8: Soil physical properties as affected by sole and integrated use of compost and mineral fertilizer

Treatments (kg ha^{-1})		Bulk density (g cm^{-3})		Moisture content (%)		Volumetric Water (m^{3}m^{-3})	
Compost	NPK fertilizer	2013	2014	2013	2014	2013	2014
0	0	1.70	1.66	6.84	3.86	11.63	6.40
	100	1.67	1.65	7.29	3.30	12.23	5.44
	175	1.69	1.65	7.17	3.38	12.14	5.60
	200	1.67	1.66	6.86	3.49	11.46	5.79
2500	0	1.69	1.65	6.88	3.42	11.63	5.65
	100	1.67	1.66	7.28	3.25	12.14	5.42
	175	1.65	1.64	6.85	3.13	11.30	5.16
	200	1.65	1.65	7.03	4.03	11.55	6.53
5000	0	1.71	1.68	6.66	3.57	11.38	5.98
	100	1.75	1.67	6.98	3.34	12.31	5.56
	175	1.73	1.67	7.12	3.36	12.31	5.63
	200	1.73	1.68	6.72	3.62	11.63	6.09
CV (%)		3.40	2.40	11.00	29.80	12.90	28.30
Lsd (0.05)							
Lsd C		0.05	0.05	0.65	0.65	1.19	1.29
Lsd NPK		0.05	0.06	0.69	0.75	1.49	1.45
Lsd C x NPK		0.09	0.09	1.30	1.29	2.57	2.59

C = compost

4.3.2 Discussion

4.3.2.1 Soil pH

Soil pH did not significantly change under all treatments even though increases were observed compared to the initial value (Table 4.2). Hati *et al.* (2007) reported that soil pH did not change significantly with application of manure and fertilizer even after 26 years. The highest pH values of 5.63 (2013) and 6.26 (2014) were obtained under combined use of 2500 kg ha^{-1} compost + 200 kg ha^{-1} NPK and sole application of 2500 kg ha^{-1} compost, respectively. Whalen *et al.* (2000) found an increase in pH of two acid soils after application of fresh manure or composted animal manure. Fatondji (2002) also reported a non-significant increase in pH value from an initial value of 3.9 to 4.3 within Zai amended with manure and crop residues and to 4.4 in flat application of manure and crop residues. Abdel-Rahman (2009) found a pH increase after composted manure application in the sahelian zone of Burkina Faso. Increased pH contributes to nutrient assimilation since most of plant nutrients are soluble and are available between pH of 5.6 to 7.5.

4.3.2.2 Soil organic carbon

There was a non-significant increase in soil organic carbon (SOC) content among the treatments especially under combined use of compost and mineral fertilizer in 2013 (Table 4.2). This can be explained by the addition of organic matter through compost application (Table 4.9). Fairhurst (2012) reported that organic inputs with C/N ratio < 16 release nutrients within a short time. Weber *et al.* (2007) found a progressive increase in % SOC after three years of compost application. On the contrary, in 2014 % SOC decreased (Table

4.2) and this can be related to the low soil moisture (Table 4.8) and the high temperature which probably had an impact on organic matter decomposition. Brown and Cotton (2011) found an increase of 3 fold over the control in organic carbon after application of compost with an average of 1.5 □ 1.2 % in the 0 - 15 cm depth. Sarwar *et al.* (2008) obtained an increase of percent SOC under a 12 t/ha and 24 t/ha compost application.

4.3.2.3 Soil total N

Soil total nitrogen content increased in all amended plots in 2013 due to addition of N through compost and mineral fertilizer applications (Table 4.3). Harris (2002) found that the application of 4 t/ha of manure approximately provided 12 kg N, 8 kg P, 32 kg K, 10 kg Mg and 34 kg Ca ha^{-1}. Furthermore, Bouajila and Sanaa (2011) found a significant increase in soil total N following the application of manure and household compost. However, nitrogen content decreased relative to the initial under the application of 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK, 2500 kg ha^{-1} compost + 200 kg ha^{-1} NPK, 5000 kg ha^{-1} compost and 5000 kg ha^{-1} compost + 200 kg ha^{-1} NPK in 2014 (Table 4.3). This can be linked to the low rainfall received in 2014, which might have influenced the nitrogen tie-up by microorganisms. Ewusi–Mensah (2009) found a lower reduction of total N content in plots amended with compost and mineral fertilizer. On the contrary, Efthimiadou *et al.* (2010) found that combined use of NPK and farmyard manure increased SOM, total N, Olsen P and ammonium acetate exchangeable K by 47, 31, 13 and 73 % respectively compared to the application of NPK through inorganic fertilizer.

4.3.2.4 Soil available P

An appreciable available P increase of 11.35 % (2013) and 87.61 % (2014) relative to the initial value (8.72 mg kg^{-1}) was observed under application of 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK and 2500 kg ha^{-1} compost with available P values of 9.71 and 16.36 mg kg^{-1} respectively (Table 4.3). This increase though not significant, can be attributed to the addition of organic matter which according to Nziguheba *et al.* (1998) contributes to the desorption of phosphate and thus improves the available P content in soil. Arthur (2009) made similar observation in Ghana after application of crop residues. Chen *et al.* (2001) demonstrated that composted straw was found to have the greatest ability to reduce the inorganic P sorption capacity of the soil, followed by composted cattle manure. Composted poultry manure also reduced the strength of P adsorption by the soil and improved the P availability (Yu *et al.*, 2013).

4.3.2.5 Exchangeable bases

Application of compost and NPK mineral fertilizer after two years (2013 and 2014) did not significantly change the exchangeable calcium and magnesium among all treatments even though an increase was observed compared to their initial values (Table 4.4). This increase was more pronounced under application of 5000 kg ha^{-1} compost for Ca and 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK for Mg. On the other hand, mean exchangeable K (1.35 $cmol_+$ kg^{-1}) and Na (0.25 $cmol_+$ kg^{-1}) were higher under application of 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK as shown in Table 4.5. Ayeni and Adeleye (2012) found a significant increase in exchangeable Ca and Mg after combined application of cattle dung and urea fertilizer from selected agro-ecological zones of Nigeria. The highest Ca was obtained under application of 5000 kg ha^{-1} cattle dung.

4.3.2.6 Exchangeable acidity

The Al^{3+} and H^+ showed a decrease in concentration relative to their initial values under application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 5000 kg ha^{-1} compost + 200 kg ha^{-1} NPK for Al^{3+} and 2500 kg ha^{-1} compost for H^+. According to Ayeni and Adeleye (2012), sole application of cattle dung and its combination with urea fertilizer decreased soil Al^{3+} and H^+ at various selected agro-ecological zones of Nigeria.

4.3.2.7 Effective cation exchange capacity and percent base saturation

Percent base saturation was relatively higher in 2014 than in 2013 in most treatments (Table 4.7) with higher values of 82.4, 80.8 and 81.3 % being recorded under application of 2500 kg ha^{-1} compost, 5000 kg ha^{-1} compost and 5000 kg ha^{-1} compost + 100 kg ha^{-1} NPK, respectively. This can be explained by the accumulation of exchangeable bases following the amendment application over the two cropping seasons. An appreciable ECEC increase of 78.18 % (2013) and 53.18 % (2014) was observed under the applications of 200 kg ha^{-1} NPK and 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK, respectively.

4.3.2.8 Soil physical properties after sole and combined application of compost and mineral fertilizer

Compost and mineral fertilizer application decreased bulk density insignificantly in

2014 compared to 2013 in all treatments (Table 4.8 and Appendix 1). This decrease can be explained by the soil structure improvement due to compost application. The lowest value of 1.64 g cm^{-3} was recorded by applying 2500 kg ha^{-1} of compost + 175 kg ha^{-1} NPK in 2014.

The high moisture and volumetric water contents observed in 2013, especially under application of 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK (7.12 % and 12.31 m^3m^{-3}) were due more to the fact that the compost improved soil moisture storage as well as the high and regular rainfall received in 2013 compared to 2014 (Figure 4.1). Stoffella *et al.* (1997) showed that composted manure has multiple benefits on the improvement of soil moisture, storage and porosity. Harris (2002) stated that the addition of manure to fields can improve water-holding capacity and soil structure.

4.4 Chemical composition of organic amendments used

4.4.1 Results

The chemical composition of raw materials (manure and cowpea haulm) and the matured compost used during the two years of the study are presented in Table 4.9. The manures used for composting during the two years of the study had similar percent N content which ranged from 0.29 to 0.35 %. Total N content of compost ranged from 1.02 to 1.22 %. Total P content of manure was higher in 2014 (1.06 %) than in 2013 (0.16 %). On the other hand, matured compost had similar P content in both years (3.01 and 3.23 %). Total N content of the matured compost was not too much different in both years (1.02 and 1.22 %). The matured compost had a C/N ratio of 5.5 and 9.0 respectively in 2013 and 2014 as shown in Table 4.9. Lignin contents of manure, cowpea haulm and matured compost were 3.80 and 2.20 %, 10.95 and 4.35 % and 6.70 and 5.55 % respectively in 2013 and 2014 while the polyphenol contents were 0.59 and 0.92 %, 0.97 and 1.35 % and 0.62 and 0.67 % respectively. Even though the lignin and polyphenol contents of the raw materials (manure and cowpea haulm) were different, the matured compost had closely the same value of lignin and polyphenol in both years.

Table 4.9: Chemical characteristics of manure, cowpea haulm and compost used

Measured parameters	**Organic amendments***					
	2013			2014		
	Manure	Cowpea haulm	Matured compost	Manure	Cowpea haulm	Matured compost
Total N (%)	0.35	2.51	1.02	0.29	1.66	1.22
Total P (%)	0.16	0.16	3.01	1.06	0.94	3.23
Total K (%)	2.06	1.93	1.53	1.74	0.89	2.09
Org. C (%)	7.85	20.75	5.60	18.62	48.68	10.90
C/N ratio	22.40	8.30	5.50	64.20	29.30	9.00
Total Ca (%)	0.20	0.06	0.22	0.03	0.07	0.20
Total Mg (%)	0.09	0.01	0.10	0.01	0.005	0.07
Lignin (%)	3.80	10.95	6.70	2.20	4.35	5.55
Polyphenol (%)	0.59	0.97	0.62	0.92	1.35	0.67

*Values are means of triplicate sample analyses

4.4.2 Discussion

Quality of organic amendments is one of the key factors determining the rate of decomposition. Manure used for this study in both years contained low major nutrients indicative of low quality (Table 4.9). Paul *et al*. (2009) reported a low total nitrogen content of manure on a dry matter basis of below 0.5 %. Harris (2002) found percent N and P ranges of 1.2 - 1.7 and 0.15 - 0.21, respectively.

Cowpea haulm on the other hand, had higher N content in both cropping years and P was higher in 2014. Composting cattle manure with the addition of cowpea haulm enhanced manure fertilizer value. Composting manure resulted in 2.5 and 4.5 times more N and P content respectively relative to the initial manure contents over the two years (Table 4.9). These results are higher than the findings of Fening *et al.* (2010) who found 53 and 102 % N increase in Ghana respectively in a 2:1 and 1:1 composted cattle manure. This high increase can be explained by the high N content of cowpea haulm (Table 4.9) and also by the fact that the manure quality was very poor. Organic carbon decreased after composting and this could be due to its use by microorganisms. Ewusi– Mensah (2009) made a similar observation after composting cowdung in Ghana.

According to Vanlauwe *et al.* (2002), organic materials with lignin content less than 15 % and polyphenol less than 4 % can be incorporated directly as soil amendment if the N content is greater than 2.5 %. The lignin content of the initial manure (2.2 - 3.8 %), cowpea haulm (4.35 - 10.95 %) and polyphenol (0.59 - 0.92 %) for manure and for cowpea haulm (0.97 - 1.35 %) (Table 4.9) were less than those found by Opoku (2011). Opoku (2011) found lignin content range of 10.1 and 16.0 % and polyphenol content range of 6.6 and 8.4 % in manure at Maradi (Niger). On the other hand, lignin and polyphenol contents of compost ranged between 6.70 and 5.55 % and 0.62 and 0.67 % in

2013 and 2014 respectively. The nitrogen content of compost (1.02 - 1.22 %) was lower than 2.5 % indicating the need to mix the compost with mineral fertilizer according to the decision support system elaborated by Vanlauwe *et al.* (2002).

4.5 Temperature and moisture content of compost

4.5.1 Results

Moisture content and temperature were monitored during the composting period in 2013 and 2014 (Figure 4.2). Compost temperature was above the ambient temperature during the whole period of two years. The highest temperature values of 50 and 52.1 ^oC were recorded after 42 and 28 days of composting in 2013 and 2014, respectively (Figure 4.2). Moisture content reached its highest value of 55.0 % and 66.3 % one (1) and four (4) weeks after the composting began in 2013 and 2014 respectively. Moisture level was more stable in 2013 than in 2014.

4.5.2 Discussion

The measurement of temperature during composting is an indirect method of assessing the decomposition of organic matter. At the onset of the composting process in 2013 and 2014, temperatures in the pile were 41.4 and 39.5 ^oC (after one week), which increased to a maximum of 49.3 and 52.1 ^oC six and four weeks afterwards (Figure 4.2) and decreased gradually till compost maturation. This can be explained by the presence and activity of microorganisms. Ngakou *et al.* (2008) reported that the first week of composting temperature is explained by the activity of mesophilic microorganisms and after few weeks these mesophilics are changed by the thermophilic micro-organisms as temperature increases. Furthermore, Tkachuk *et al.* (2013) observed two phases of temperature during the composting process: the biooxidative phase and the maturation phase. The biooxidative phase generally begins within the first few days of composting, when primarily mesophilic organisms decompose organic matter, resulting in an increase in temperature to over 40 °C. As the temperature increases, thermophilic organisms proliferate and decompose organic matter and inactivate many pathogens.

Moisture content of the compost decreased from 70.0 to 40.3 % and 59.2 to 44.2 % in 2013 and 2014 during composting process (Figure 4.2). These ranges were favourable for the development and activity of microorganisms. This has been reported by Augustin and Rahman (2010) who found 50 % moisture content for good development and activity of microorganisms.

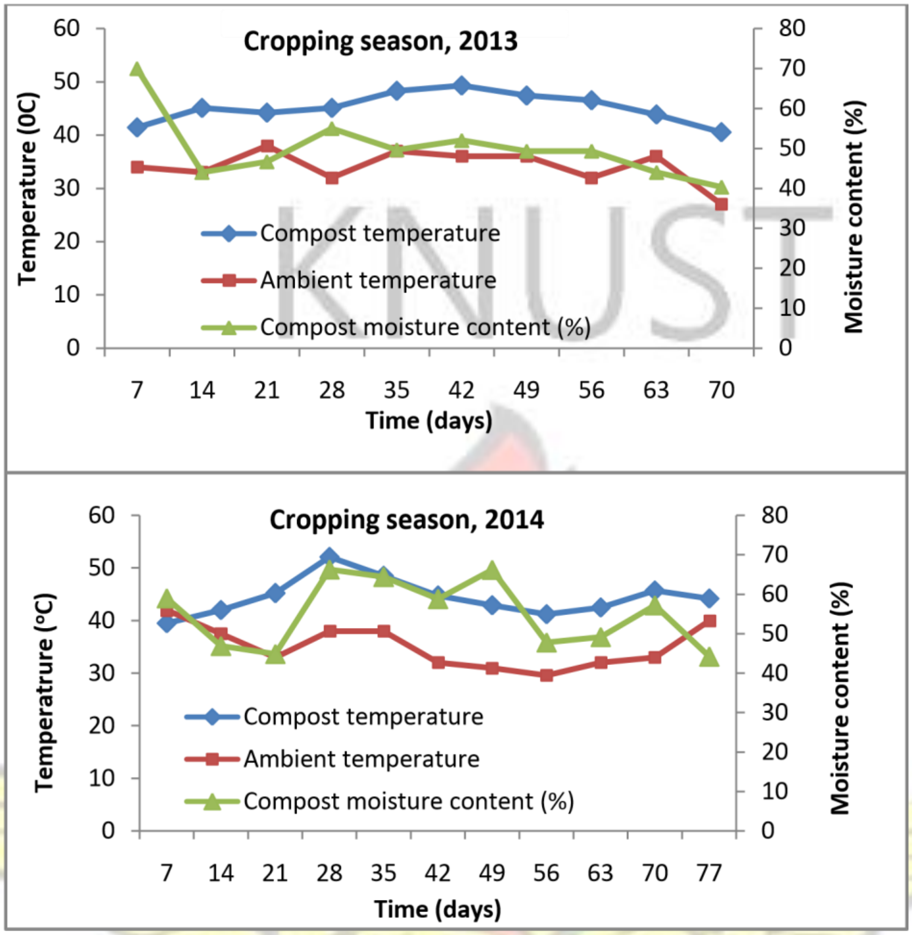

Figure 4.2: Temperature and moisture changes during the composting periods

4.6 Compost decomposition and nutrient release patterns

4.6.1 Results

4.6.1.1 Decomposition of compost under field conditions

The decomposition of compost was monitored under field conditions during the 2013 and 2014 cropping seasons as shown in Figure 4.3. There was a gradual decrease of the mass remaining in the litterbags over time during the two cropping seasons. After 21 and

14 days of decomposition, 26.50 and 32.25 % mass loss was observed in 2013 and 2014 respectively. This mass loss showed a rapid decomposition pattern in 2014. The remaining compost in the litter bags after 84 days (almost the end of cropping season) of exposure were 59.67 and 43.5 % in 2013 and 2014 cropping seasons respectively. In both years, the decomposition factor was the same (k = 0.07 $week^{-1}$) indicating a low decomposition rate of the compost.

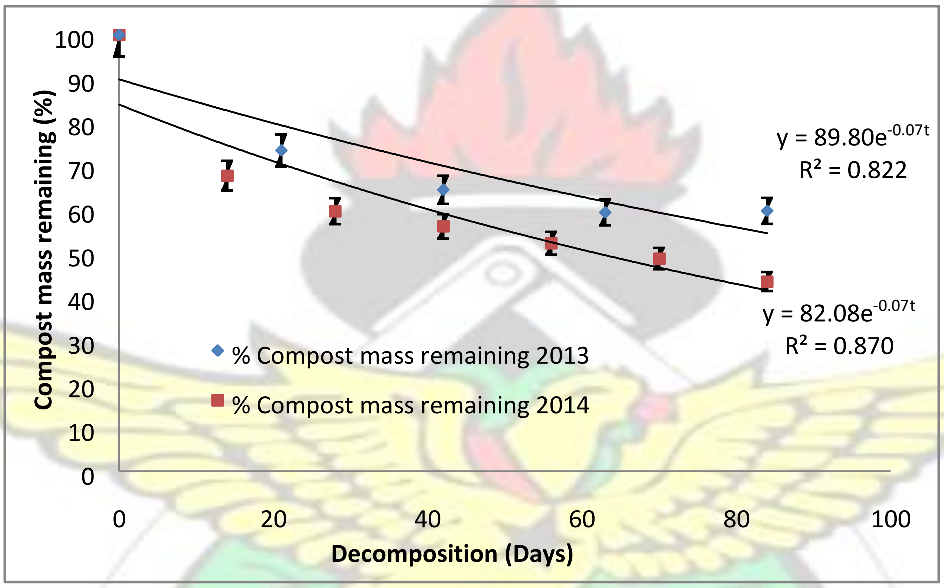

Figure 4.3: Compost decomposition over time under the field conditions during 2013 and 2014 cropping seasons (Bars = standard error).

4.6.1.2 Relationship between mass loss and rainfall

Rainfall pattern is important for the decomposition of compost under field conditions since it influences the soil moisture content which has an impact on microbial activities. The correlation between mass loss and cumulative rainfall were 99.3 and 96.4 % in 2013 and 2014 respectively as shown by Figure 4.4. The higher R^2 in 2013 was due to higher rainfall.

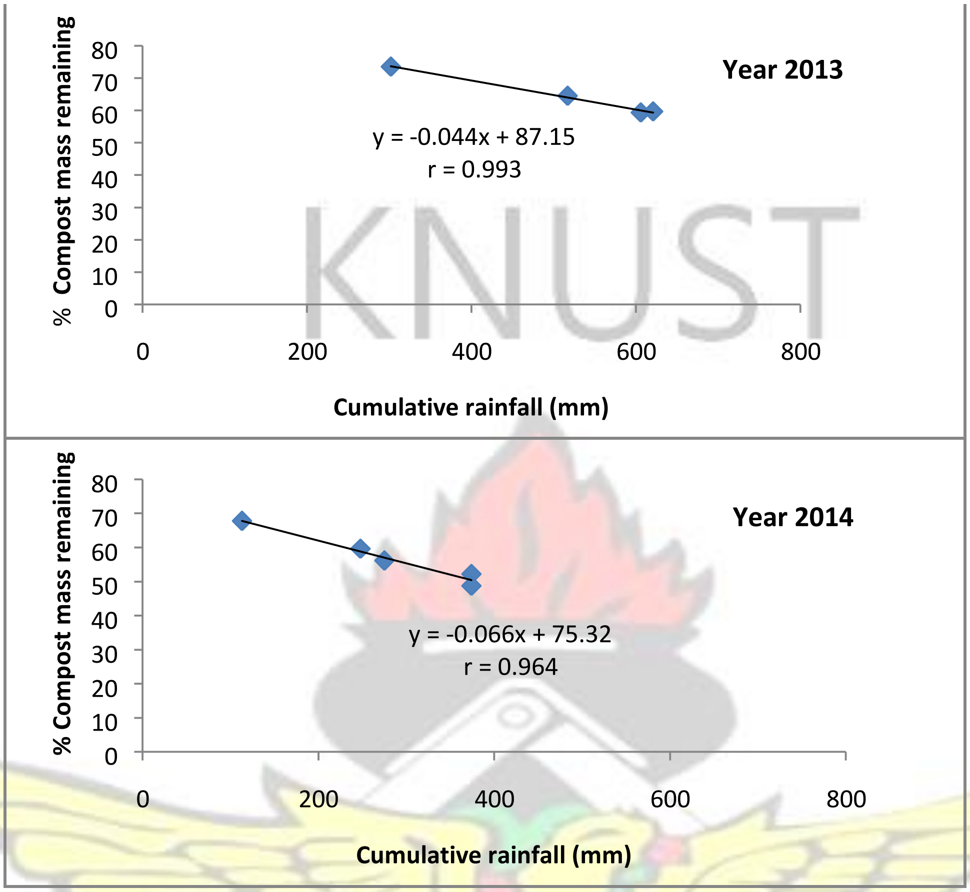

Figure 4.4: Relationship between % mass loss and cumulative rainfall received during compost decomposition under field conditions

4.6.1.3 Nutrient release from compost under field conditions

For good management of an organic resource, it is fundamental to understand how it releases nutrients over time under field conditions. Thus, compost samples were analyzed after each sampling time in order to find out its nutrient release pattern over time. In 2013 cropping season, potassium (K) was the most released nutrient with a maximum value of 97 %, followed by phosphorus (P) (74 %) and nitrogen (N) (31 %) as shown in Figure 4.5. These maximum values were reached sixty three (63) days of decomposition in 2013. Potassium and phosphorus were immobilized between 63 and 84 days after decomposition. Immobilization of nitrogen occurred between 21 - 42 days and 14 – 28 days of decomposition in 2013 and 2014, respectively. In 2014 cropping season, K was mineralized throughout the decomposition period. Phosphorus was immobilized between 42 – 70 days of decomposition. Potassium (K) and phosphorus (P) release patterns followed the same trend as compost mass loss in 2013 and 2014 cropping seasons. In 2014, the higher percentages of K, P and N release of 99, 60 and 58 % respectively were observed after 84 days of decomposition (Figure 4.5).

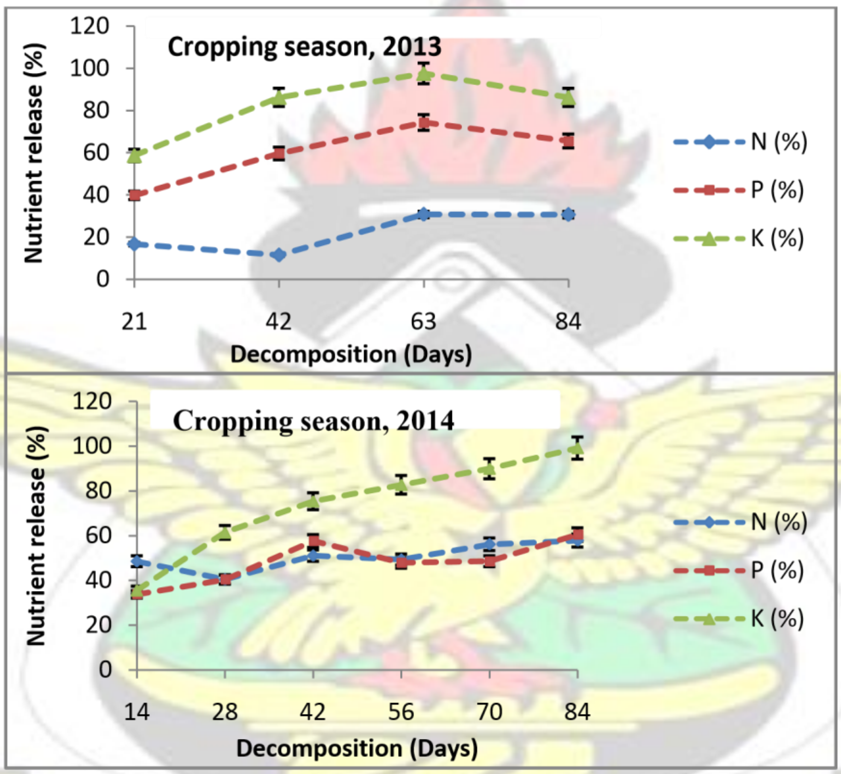

Figure 4.5: Nitrogen, phosphorus and potassium release patterns under field conditions during the 2013 and 2014 cropping seasons (Bars represent standard error)

Calcium and magnesium were mineralized between 21 – 63 days with maximum release values of 41 and 21 % and immobilized between 63 – 84 days of decomposition in 2013. A slight immobilization occurred for carbon between 42 – 63 days of decomposition in

2013 and its highest percent release (44 %) after 42 days (Figure 4.6). In 2014, calcium and magnesium were immobilized between 14 – 28 days of decomposition after which mineralization occurred till the end of bags exposure. On the contrary, carbon was mineralized between 14 – 42 days, after which it was immobilized till the end of decomposition. The highest Ca and Mg values of 51 and 40 % were obtained after 84 days of decomposition while at 42 days carbon release reached its highest percent value of 50 % (Figure 4.6).

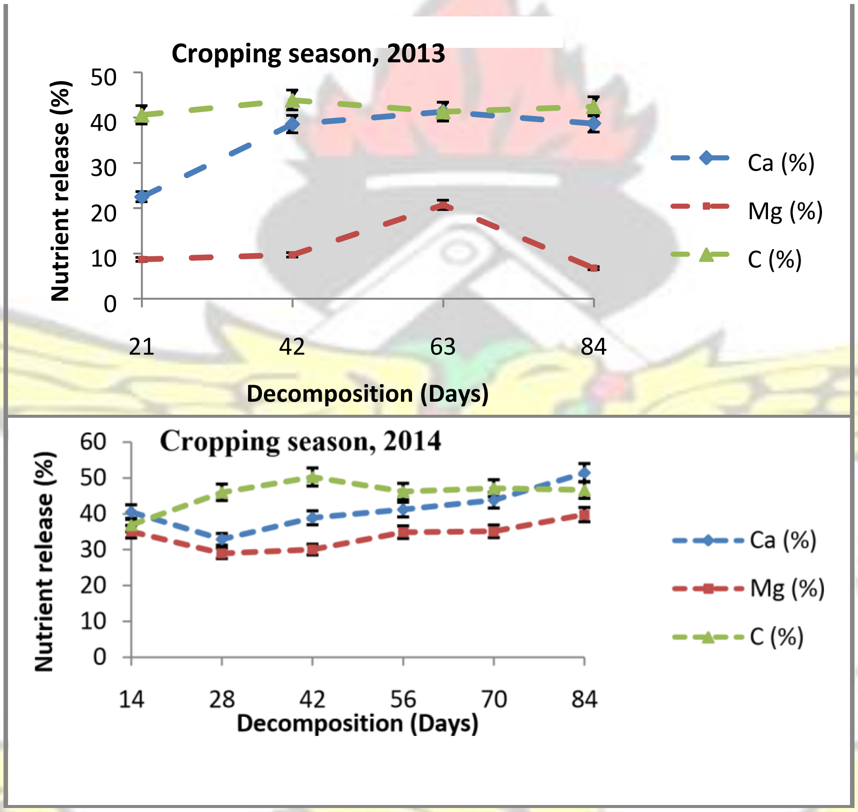

Figure 4.6: Calcium, magnesium and carbon released patterns under field conditions during the 2013 and 2014 cropping seasons (bars represent standard error)

Mass remaining and nutrient release were strongly negatively correlated especially for N,P and K during the two cropping seasons as shown in Table 4.10, indicating that the nutrient concentration decreased with time.

Table 4.10: Correlation between mass remaining and nutrient release from compost under field conditions during the two cropping seasons.

2013	% mass remaining	% N	% P	% K	% Ca	% Mg	% C
% mass remaining	1						
% N	-0.69	1					
% P	-0.975*	0.66	1				
% K	-0.947*	0.516	0.984**	1			
% Ca	-0.955*	0.458	0.958*	0.983**	1		
% Mg	-0.402	0.398	0.589	0.581	0.426	1	
% C	-0.395	-0.341	0.323	0.446	0.58	-0.297	1
2014	% mass remaining	% N	% P	% K	% Ca	% Mg	% C
% mass remaining	1						
% N	-0.707	1					
% P	-0.82*	0.655	1				
% K	-0.987***	0.659	0.85*	1			
% Ca	-0.706	0.916**	0.586	0.614	1		
% Mg	-0.541	0.77	0.295	0.422	0.936*	1	
% C	-0.663	0.224	0.791	0.764	0.051	-0.237	1

*, ** and *** Correlation is significant at 0.05, 0.01 and 0.001 respectively

4.6.1.4 Nutrient release from compost under laboratory conditions

Nutrient release patterns of composted cattle manure was also monitored under controlled laboratory conditions. Nitrogen release was highest on day one (1), i.e. 8 % (2013) and 17

% (2014) and decreased continuously but still above the control till the end of the incubation period in both years (Figure 4.7). Phosphorus release followed the same trend as nitrogen and was still higher than the control even though in 2014 it was close to zero as shown in Figure 4.7.

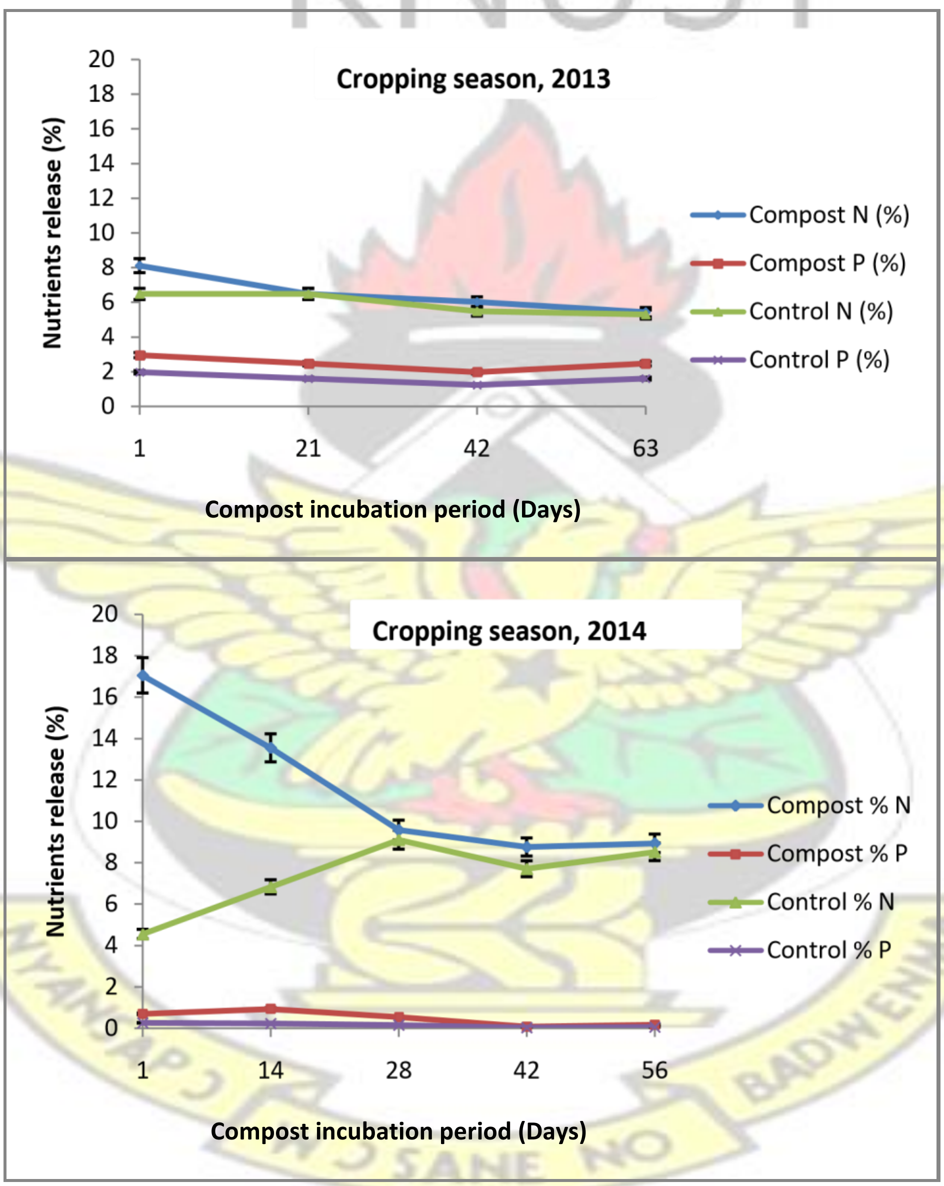

Figure 4.7: Compost N and P release patterns under laboratory conditions (Bars represent standard error)

Under laboratory conditions, nitrate - N ($NO_3^- - N$) release decreased over the period of incubation with the highest values of 9.37 and 7.59 % observed at day one in 2013 and 2014 respectively (Figure 4.8). At the same time, ammonium - N ($NH_4^+ - N$) kept rising in 2013 and reached the highest value of 9.92 % at 63 days of incubation, while it decreased gradually in 2014.

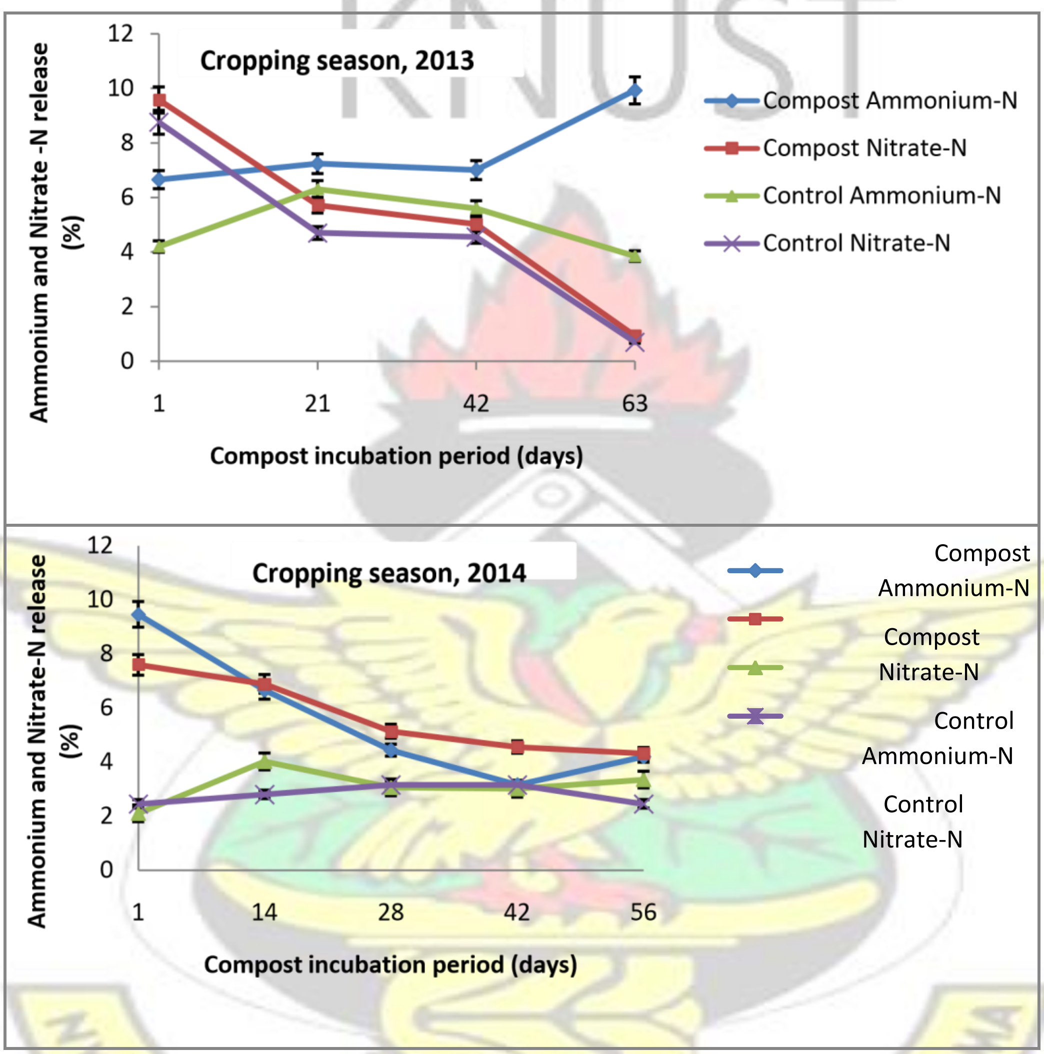

Figure 4.8: Compost ammonium - N and nitrate - N release patterns under laboratory conditions (Bars represent standard error)

Calcium (Ca) and magnesium (Mg) release patterns were also monitored under laboratory conditions. Compost released the highest Ca and Mg values of 1.82 and 0.81 % in 2013 respectively after 42 days of incubation. On the other hand, 5.28 and 0.87 % Ca and Mg were released respectively in 2014 at day one (Figure 4.9). Calcium was immobilized at one and 63 days after incubation in 2013 and at 42 days in 2014.

Magnesium was also immobilized throughout the compost incubation and from 28 days of incubation period respectively in 2013 and 2014 cropping seasons.

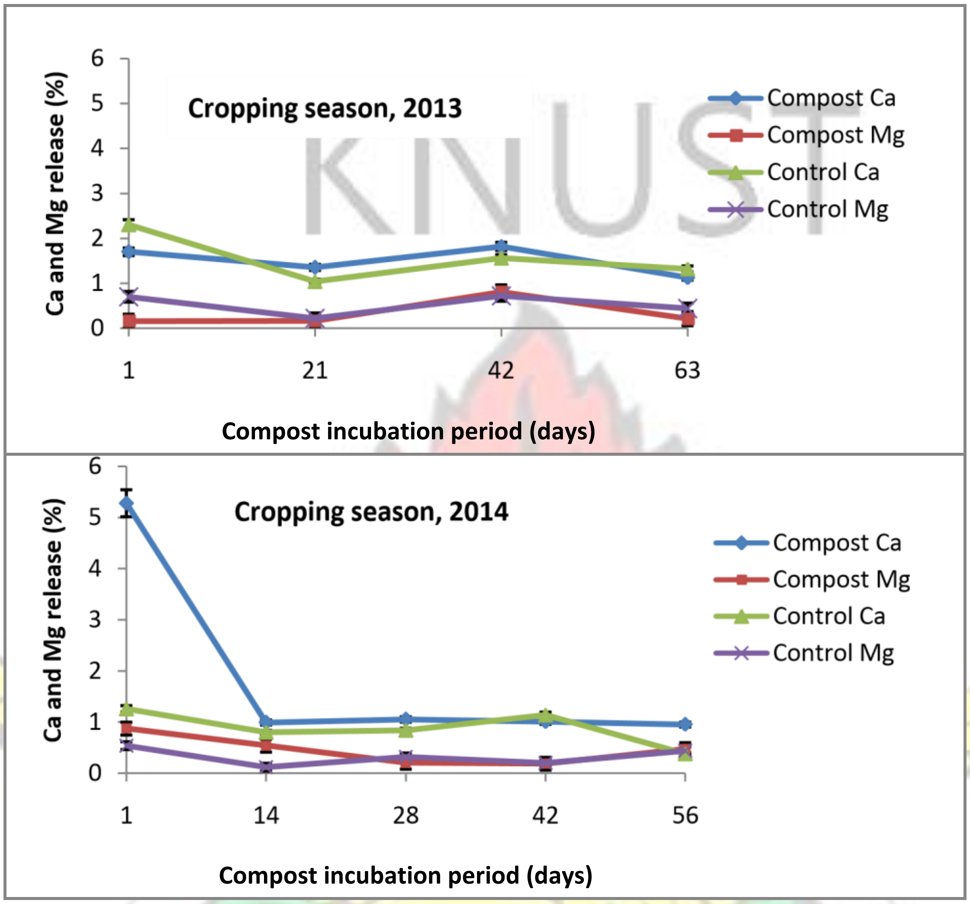

Figure 4.9: Compost Ca and Mg release patterns under laboratory conditions (Bars represent standard error)

4.6.2 Discussion

4.6.2.1 Decomposition of compost under field conditions

After 84 days (12 weeks) of decompostion, there were still 59.6 and 43.5 % of undecomposed matured compost in 2013 and 2014 respectively (Figure 4.3). This was against only 8 % of the undecomposed manure in zai pits after 81 days of exposure found by Fatondji *et al.* (2009). The difference between the two findings could be explained by the microclimate created within Zai which allowed high microorganism activity.

However, this decomposition rate is similar to the findings of Esse *et al.* (2001) who found in nylon bags at 10 weeks manure decomposition of 38 % on „Glacis‟ and „Dallol‟ soils in South-west region of Niger. In addition, Partey *et al.* (2011) reported 31 % of decomposing leaf material remaining (*Acacia auriculiformis*) after 12 weeks of decomposition.

Even though decomposition of matured compost increased gradually till the end of cropping season, it was low in both years and this could be linked to the rainfall pattern (Figure 4.1) particularly in 2014. In fact when rainfall decreases, the moisture content of soil also decreases and activity of microorganisms is negatively affected (Augustin and Rahman, 2010). The low observed compost decomposition is contrary to the findings of Tetteh (2004) in Ghana who found a rapid decomposition phase of organic materials during the earliest weeks of decomposition. The difference in both findings may be due to the climatic conditions (moisture and ambient temperature) as well as population and diversity of microorganisms. Under dry sahelian conditions of Niger, decomposition is mainly dominated by the macro fauna (termites essentially) (Fatondji *et al.*, 2009). Quality of the material (lignin content), and soil conditions of the study site can influence decomposition rate as reported by Dhanya *et al.* (2013). According to Freymann *et al.* (2008), termites can quickly remove large amounts of mammalian dung especially in the dry season, where on average about 1/3 of dung is removed within one month.

4.6.2.2 Nutrient release patterns of compost under field conditions

Nutrient release of the compost had different patterns under field and under the laboratory environmental conditions, due to environmental conditions particularly temperature which easily influences the activity of microorganisms. Nutrients release, especially P and K (Figure 4.5) followed the same decomposition pattern as found by Esse *et al.* (2001) and Fatondji *et al.* (2009) in Niger during manure decomposition. In both years, K was the most released nutrient with maximums values of 97 and 99 %, followed by P with 74 and 60 % and N with 34 and 57 % (Figure 4.5). The high potassium release was due to the fact that potassium was already in the inorganic form within the compost while N and P can only be mineralized from organic to inorganic form. The release patterns discovered during this study followed the same trend found by Augustin and Rahman (2010), who demonstrated that 90 % K, 80 % P and 50 % N of the total nutrient within composted cattle manure were released and made available to the plant during the first crop growing season.

Rainfall pattern in the study area may have affected nutrient release and availability especially N. Hagedorn *et al.* (1997) showed that with low rainfall intensities, mineralization occurred, doubling top soil mineral N concentrations within 5 days after wetting. In contrast, under heavy rains at the onset of the rainy season, top soil mineral N decreased by 50 and 70 % within the first two weeks. Nitrogen immobilization observed between 21 – 42 and 14 – 28 days of decomposition respectively in 2013 and 2014 cropping seasons could be due to nitrogen tie - up by microorganisms. Furthermore, it could be as a result of low moisture resulting from low rainfall at the study area during the period (Figure 4.1). Partey *et al.* (2011) however, found N immobilization between 4 and 8 weeks of decomposition of leaves of four species (*Acacia auriculiformis, Senna spectabilis, Leucaena leucocephala and Gliricidia sepium*). Nitrogen immobilization observed in this study could also be due to increased carbon release as it has been shown by Moore *et al.* (2000) that N immobilization increased with soil organic carbon increase. Organic carbon release was biphasic in both years (Figure 4.6). It reached the values of 44 and 50 % in 2013 and 2014 respectively after 42 days of decomposition and decreased till the end. This trend could be due probably to the use of organic carbon by microorganisms. Magnesium and calcium release fluctuated over time in both years with high release over time in 2013 than 2014 which could be due to the high correlation between mass remaining and rainfall.

4.6.2.3 Nutrient release patterns of compost under laboratory conditions

Compost total N and P release under laboratory conditions in both study years decreased gradually from the onset of incubation till the end but were always relatively higher than the control (Figure 4.7). Nitrogen and phosphorus followed a similar trend in both years with maximum release of 8 (2013) and 17 % (2014) for N and 3 (2013) and 1 % (2014) for P at day one (1) of the incubation. Nitrogen release was highest in 2014 while phosphorus release was highest in 2013 and both nutrients were mineralized during the whole incubation period. These findings followed the trend of total N mineralization found by Azeez and Van Averbeke (2010) during 120 days of manure incubation. On the contrary Jost *et al.* (2013) found a net N immobilization after 2 weeks incubation of cattle manure. Furthermore, Fening *et al.* (2010) found a net immobilization after 1 week of incubation of 1:1 compost (- 57 mg kg^{-1}) and 2:1 compost (-59 and - 9 mg kg^{-1}) after two weeks. The difference between these findings and the results of this study could be attributed to the low C:N ratio of the matured compost (5.5 and 9.0) of this study which is favorable for mineralization. In 2013, Ammonium - N release increased over time while nitrate - N is decreasing (Figure 4.8). This could be explained by the fact that nitrate - N is the most preferentially absorbed nutrient compared to ammonium - N by crops and also more leachable (Figure 4.8). These findings are contrary to those of Ewusi–Mensah (2009) in the case of nitrate - N release. He reported a net nitrate immobilization throughout the period of incubation for a 1:1compost.

4.7 Effect of composted cattle manure and inorganic fertilizer on the growth parameters of pearl millet and cowpea under strip cropping

4.7.1 Results

Table 4.11 shows pearl millet height (at harvest) and LAI during the 2013 and 2014 cropping periods. The highest values of plant height were recorded by combined application of 2500 kg ha^{-1}compost + 175 kg ha^{-1} NPK in 2013 (190.9 cm) and 2014 (149.0 cm). Furthermore, plant height was significantly different ($P < 0.001$) among the treatments during the 2013 cropping season. On the contrary, in 2014 only sole application of mineral fertilizer significantly ($P < 0.001$) affected plant height as shown in Table 4.11. The least plant heights of 114.4 and 151.6 cm were obtained following application of 5000 kg of compost in 2013 and 2014 cropping seasons respectively.

Despite the fact that leaf area index (LAI) was not significant in all treatments in 2013, it was relatively higher than in 2014 as shown in Table 4.11. The relatively higher values of LAI in 2013 could conducted to better light interception which could have contributed to higher photosynthesis and consequently good crop growth as well as grain filling. The highest LAI was recorded under application of 5000 kg ha^{-1} + 175 kg ha^{-1} of NPK with values of 2.08 and 1.49 m^2 m^{-2} respectively during 2013 and 2014 cropping seasons.

Table 4.11: Pearl millet height and leaf area index under different treatments

Treatments (kg ha^{-1})		Millet height (cm)		LAI (m^2 m^{-2})	
Compost	NPK fertilizer	2013	2014	2013	2014
0	0	172.00	115.70	1.91	1.03
	100	180.60	139.80	2.29	1.33
	175	173.00	137.50	1.75	1.38
	200	171.20	137.90	2.07	1.17
2500	0	176.40	135.70	2.23	1.11
	100	175.20	138.00	2.10	1.39
	175	190.90	149.00	2.06	1.27
	200	185.20	142.50	1.92	1.46
5000	0	151.60	114.40	1.82	1.12
	100	173.70	143.10	2.31	1.35
	175	188.80	141.30	2.08	1.49
	200	166.70	142.50	1.80	1.33
Fpr.					
Compost		< 0.001	0.091	0.380	0.522
M. Fertilizer		< 0.001	< 0.001	0.440	0.026
C x M.F		< 0.001	0.229	0.760	0.787
Lsd (0.05)					
Lsd C		4.830	7.880	0.380	0.180
Lsd NPK		5.580	9.100	0.440	0.210
Lsd $_{C \times M.F}$		9.670	15.440	0.760	0.360

C = compost, M.F = mineral fertilizer

Crop growth rate (CGR) of pearl millet during the 2013 and 2014 cropping seasons are presented in Figure 4.10. Application of 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK had the highest growth rate (2.92 g/m^2/day) followed by 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK

(2.67 g/m^2/day) in 2013. However in 2014, the application of sole 200 kg ha^{-1} NPK recorded the highest millet growth rate of 2.00 g/m^2/day followed by 5000 kg ha^{-1} compost + 100 kg ha^{-1} NPK (1.96 g/m^2/day).

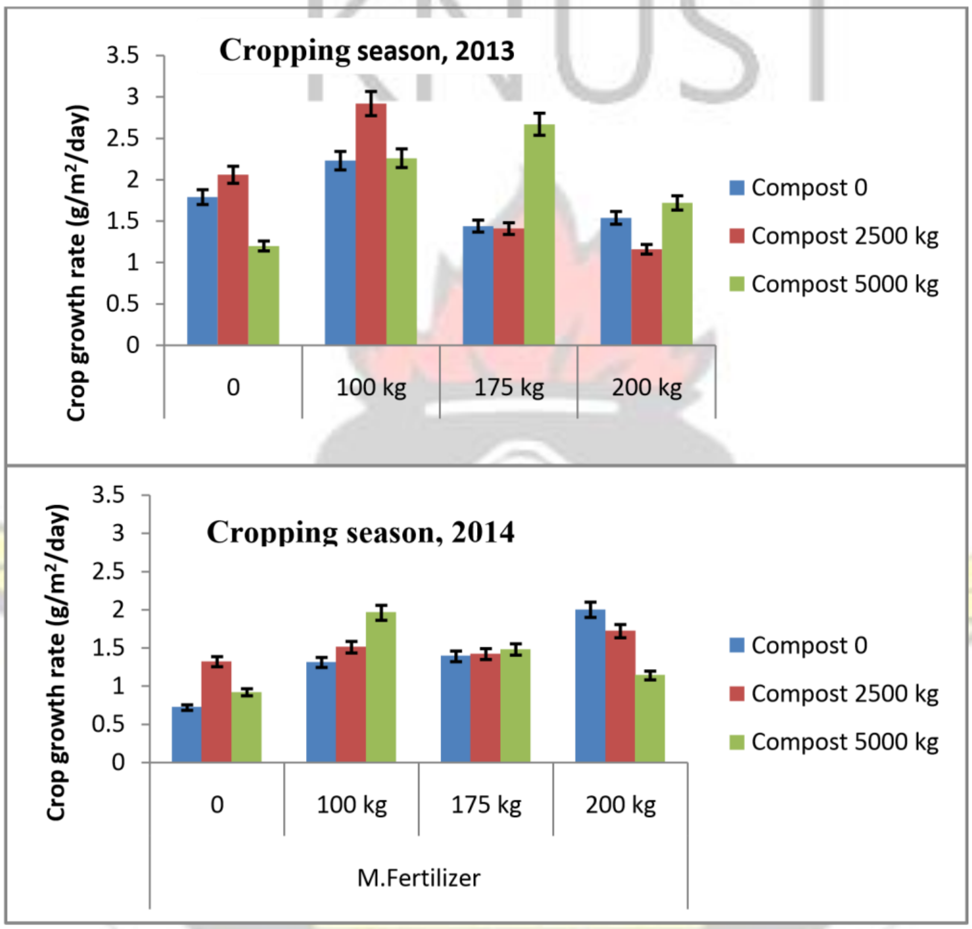

Figure 4.10: Crop growth rate as affected by treatments during the 2013 and 2014 cropping seasons (Bars represent standard errors)

Net assimilation rate (NAR) of pearl millet was calculated during the 2013 and 2014 cropping seasons (Figure 4.11). The lowest net assimilation rates of 0.63 and 0.61 g/m^2/day were recorded under the application of 5000 kg ha^{-1} compost and control in 2013 and 2014 cropping seasons respectively. On the other hand, highest NAR of 1.42 g/m^2/day

(2013) and 1.54 g/m^2/day (2014), were all found under the application of 2500 kg ha^{-1} compost + 100 kg ha^{-1}.

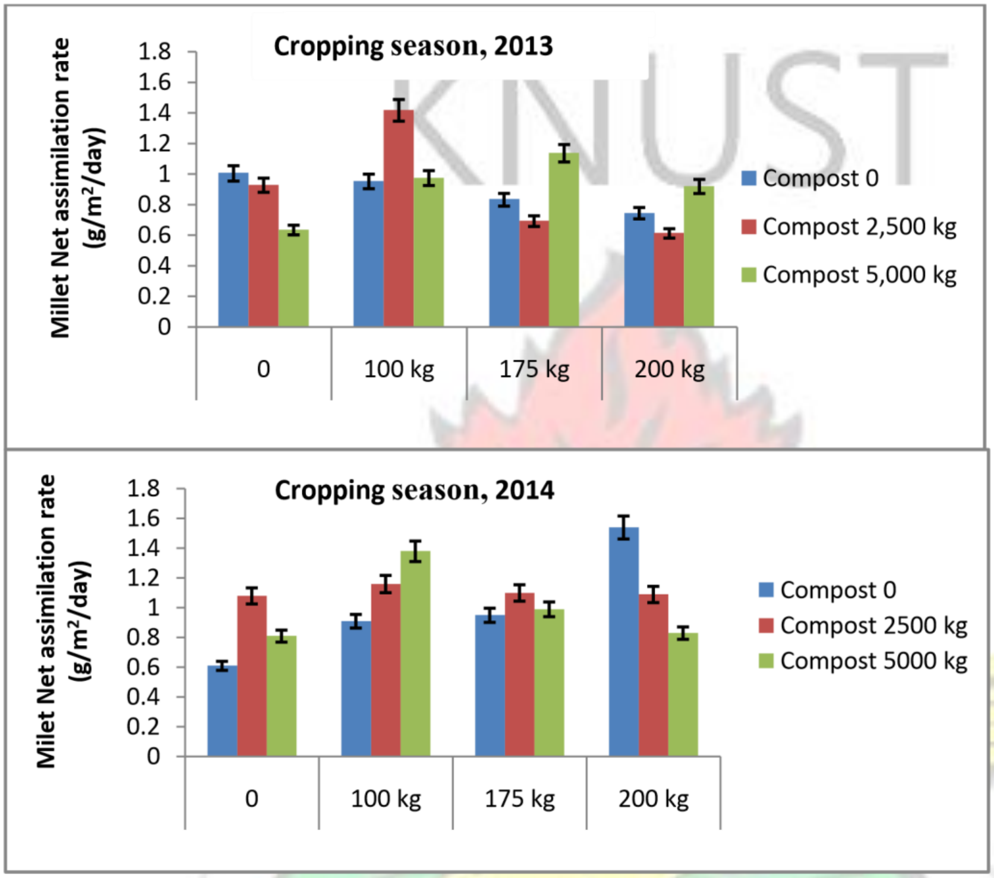

Figure 4.11: Pearl millet net assimilation rate under treatments during the 2013 and 2014 cropping seasons (Bars represent standard errors)

Relationship between crop growth rate and net assimilation rate of pearl millet is as shown in Figure 4.12. In both 2013 and 2014 cropping seasons, pearl millet net assimilation rate was highly correlated with crop growth rate with a correlation coefficient (r) of 88 % each.

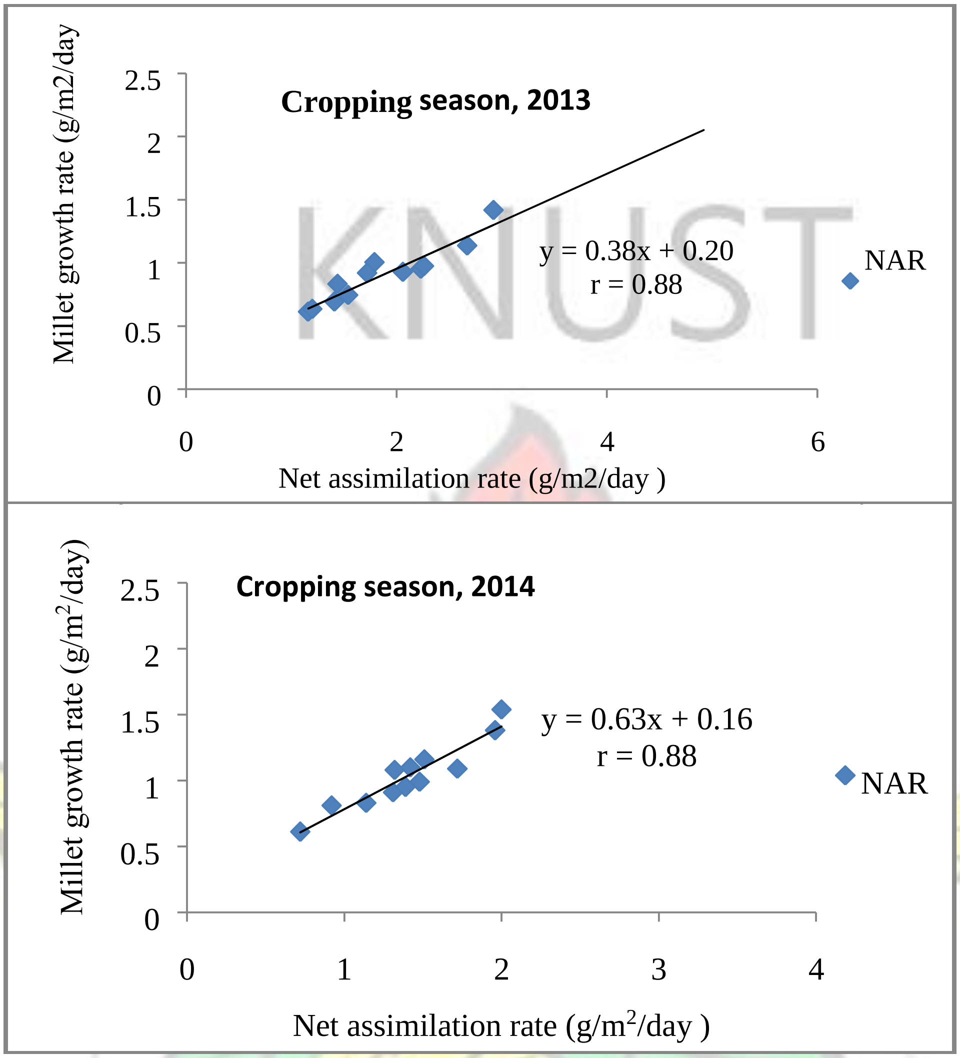

Figure 4.12: Relationship between pearl millet growth rate and net assimilition rate during the 2013 and 2014 cropping seasons

4.7.1.2 Effect of composted cattle manure and inorganic fertilizer on the yield of pearl millet and cowpea under strip cropping

Pearl millet grain yields during the 2013 and 2014 cropping seasons resulting from the sole and combined application of composted cattle manure and mineral fertilizer are presented in Table 4.12. The application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK recorded the highest pearl millet grain yield of

1762 (2013) and 866 kg ha^{-1} (2014) which were 133 and 71 % over the control. Significant grain yields were observed between the sole and combined use of compost and mineral fertilizer ($P_C = 0.009$, $P_{MF} < 0.001$, $P_{C \times MF} < 0.001$) in 2013. However, only sole compost and sole mineral fertilizer applications were significant ($P_C = 0.007$, $P_{MF} < 0.001$) in 2014 cropping season (Table 4.12). In both years, sole compost and sole NPK application responses were quadratic (P = 0.003 (2013) and 0.007 (2014) for compost and P = 0.002 (2013) and P < 0.001 (2014) for NPK). The interaction was quadratic (P < 0.001) only in 2013, indicating a peak of millet grain response to the combined application of compost and NPK fertilizer. After this peak, increasing the amount of both amendments did not lead to pearl millet grain yield increase. The lowest pearl millet grain yields were observed under 5000 kg ha^{-1} compost and 2500 kg ha^{-1} compost with 737 (2013) and 431 kg ha^{-1}(2014) which represented a decrease of 2 % and 15 % over the respective controls.

Table 4.12: Pearl millet grain yield as affected by sole and integrated application of compost and mineral fertilizer

Treatments (kg ha^{-1})		Grain yield (kg ha^{-1})	
Compost	NPK fertilizer	2013	2014
0	0	755	507
	100	1225 (62.3)	544 (7.3)
	175	1144 (51.5)	550 (8.5)
	200	1246 (65.0)	525 (3.6)
2500	0	1527 (102.3)	431 (-15.0)
	100	905 (19.9)	866 (70.8)
	175	1762 (133.4)	691 (36.3)
	200	1395 (84.8)	647 (27.6)

5000	0	737 (-2.4)	492 (-3.0)
	100	1347 (78.4)	716 (41.2)
	175	1732 (129.4)	734 (44.8)
	200	918 (21.6)	665 (31.2)
Fpr.			
Compost (C)		0.009	0.007
Lin.		0.329	0.006
Quad.		0.003	0.007
M.Fertilizer (M.F)		< 0.001	< 0.001
Lin.		0.011	0.016
Quad.		0.002	< 0.001
C x M.F		< 0.001	0.113
Lin.		0.576	0.220
Quad.		< 0.001	0.228

Lin. = linear, Quad. = quadratic, Values in bracket = % increase over the control

Pearl millet straw yields during the 2013 and 2014 cropping seasons following the sole and combined application of composted cattle manure and mineral fertilizer are presented in Table 4.13. The highest pearl millet straw yields of 6750 (2013) and 4750 kg ha^{-1} (2014) were recorded under the application of 5000 kg ha^{-1} compost + 100 kg ha^{-1} NPK and 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK respectively. These represented increases of 93 and 201 % over the control in 2013 and 2014. Only the sole mineral fertilizer application had significant effect (P = 0.004) on straw yield in 2013, while sole and combined use of compost and mineral fertilizer significantly affected the straw yield ($P_C < 0.001$, $P_{MF} < 0.001$, $P_{CxMF} = 0.001$) in 2014 cropping season (Table 4.13). The lowest pearl millet straw yields of 3500 and 1533 kg ha^{-1} were recorded under the control for both years. Straw yield response was quadratic (P_c = 0.001, P_{MF} = 0.02, P_{CxMF} = 0.001) under application of compost and its interaction with NPK in 2014 and under NPK application (P = 0.004) only in 2013.

Table 4.13: Pearl millet straw yield as affected by sole and integrated application of compost and mineral fertilizer

Treatments (kg ha^{-1})		Straw yield (kg ha^{-1})	
Compost	NPK fertilizer	2013	2014
0	0	3500	1533
	100	5000 (42.9)	2167 (41.4)
	175	3917 (11.9)	1833 (19.6)
	200	5250 (50.0)	3500 (128.3)
2500	0	4250 (21.4)	2850 (85.9)
	100	4500 (28.6)	4125 (169.1)
	175	4583 (30.9)	4750 (209.9)
	200	4050 (15.7)	4000 (160.9)
5000	0	3667 (4.8)	2125 (38.6)
	100	6750 (92.9)	2250 (46.8)
	175	4583 (30.9)	2125 (38.6)
	200	4583 (30.9)	2583 (68.5)
Fpr.			
Compost (C)		0.235	< 0.001
Lin.		0.173	0.944
Quad.		0.304	< 0.001
M.Fertilizer (M.F)		0.004	< 0.001
Lin.		0.268	< 0.001
Quad.		0.024	0.431
C x M.F		0.057	< 0.001
Lin.		0.252	0.011

Quad.	0.483	< 0.001

Lin. = linear, Quad. = quadratic, Values in bracket = % increase over the control

Cowpea grain yields under sole and combined application of composted cattle manure and mineral fertilizer are presented in Table 4.14. Grain yields were low during both years and fluctuated between 49 kg ha^{-1} in 2014 and 360.5 kg ha^{-1} in 2013. Cowpea grain yields were higher during 2013 cropping season than 2014 under all treatments except under the application of 5000 kg ha^{-1} compost + 75 kg ha^{-1} DAP. The year affected significantly (P < 0.001) cowpea grain yield (Appendix 3). The lowest cowpea grain yield were obtained under control for both years. The highest yields of 360.5 and 389 kg ha^{-1} were obtained by applying 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP and 5000 kg ha^{-1} compost + 75 kg ha^{-1} DAP in 2013 and 2014 respectively. These yields lead to 183 (2013) and 694 % (2014) increases over the control. For both years, there was no significant interaction between compost and mineral fertilizer application. Sole compost application had significant effect (P <.001 in 2013 and P = 0.003 in 2014) on cowpea grain yield for both years. Sole application of DAP significantly (P = 0.038) affected cowpea grain yield only in 2013 cropping season. Cowpea grain yield response was quadratic (indicating a peak of grain yield response) under compost application (P < 0.001) in 2013, under DAP application in 2014 (P = 0.019) and under combined use of compost and DAP (P = 0.001) in 2013 cropping season.

Table 4.14: Cowpea grain yield as affected by compost and diamonium phosphate application

Treatments ($kg\ ha^{-1}$)		Grain yield ($kg\ ha^{-1}$)	
Compost	DAP fertilizer	2013	2014
0	0	127.3	49
	50	169.7 (33.3)	94 (91.8)
	75	177 (39.0)	91 (85.7)
	100	203 (59.5)	109 (122.5)
2500	0	299 (134.9)	95 (93.9)
	50	360.5 (183.2)	242 (393.9)
	75	305.7 (140.1)	201 (310.2)
	100	303.5 (138.4)	185 (277.6)
5000	0	220.5 (73.2)	136 (177.6)
	50	359.5 (182.4)	306 (524.5)
	75	225 (76.8)	389 (693.9)
	100	245.7 (93.1)	209 (326.5)
Fpr.			
Compost (C)		< 0.001	0.003
Lin.		< 0.001	< 0.001
Quad.		< 0.001	0.841
M.Fertilizer (M.F)		0.038	0.060
Lin.		0.601	0.154
Quad.		0.093	0.019
C x M.F		0.340	0.609
Lin.		0.169	0.755
Quad.		0.001	0.867

Lin. = linear, Quad. = quadratic, Values in bracket = % increase over the control

Cowpea haulm yield following the sole and combined application of composted cattle manure and mineral fertilizer is shown in Table 4.15. For all treatments, cowpea haulm yields were greater in 2013 than 2014 cropping season and the year effect was significant ($P < 0.001$) (Appendix 3). The highest haulm yield in 2013 (723 kg ha^{-1}) was recorded under 2500 kg ha^{-1} compost + 75 kg ha^{-1} DAP while 5000 kg ha^{-1} compost + 75 kg ha^{-1} DAP produced 475 kg ha^{-1} in 2014. However, application of 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP recorded the lowest haulm yield of 405 kg ha^{-1} in 2013 contrary to 2014 where the control had the lowest cowpea haulm yield of 97 kg ha^{-1}.

Significant differences ($P = 0.001$ and $P = 0.023$) were found under the sole compost application in 2013 and 2014. Compost-mineral fertilizer interaction was significant ($P < 0.001$) only in 2013. On the other hand, cowpea yield response was quadratic ($P < 0.001$) under sole application of compost in 2013.

Table 4.15: Cowpea haulm yield as affected by compost and mineral fertilizer treatments

Treatments (kg ha^{-1})		Haulm yield (kg ha^{-1})	
Compost	DAP fertilizer	2013	2014
0	0	423	97
	50	433 (2.4)	158 (62.9)
	75	404 (-4.5)	118 (21.7)
	100	481 (13.7)	199 (105.2)
2500	0	662 (56.5)	228 (135.1)
	50	405 (-4.3)	342 (252.6)
	75	723 (70.9)	294 (203.1)
	100	451 (6.6)	270 (178.4)
5000	0	429 (1.4)	229 (136.1)
	50	544 (28.6)	275 (183.5)
	75	517 (22.2)	475 (389.7)

100	463 (9.5)	228 (135.1)
Fpr.		
Compost (C)	0.001	0.023
Lin.	0.080	0.012
Quad.	< 0.001	0.237
M.Fertilizer (M.F)	0.052	0.421
Lin.	0.766	0.404
Quad.	0.408	0.160
C x M.F	< 0.001	0.539
Lin.	0.789	0.894
Quad.	0.717	0.997

Lin. = linear, Quad. = quadratic, Values in bracket = % increase over the control

4.7.2 Discussion

4.7.2.1 Pearl millet growth parameters as affected by sole and integrated use of compost and mineral fertilizer

Significant differences ($P < 0.001$) of plant height of pearl millet were observed under compost and NPK application in 2013 cropping season. Highest plant heights of 190.9 and 149.0 cm were all obtained under the application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK in 2013 and 2014. There was a synergistic effect when composted cattle manure and NPK fertilizer were combined ($P < 0.001$) during the 2013 cropping season. On the contrary, in 2014, the interaction was not significant indicating an additive effect of both amendments (Table 4.11). These findings are in agreement with the results of ElLattief (2011), who obtained a greater millet height of 145.6 cm by applying 75 % of NPK recommended rate and 5000 kg ha^{-1} of farm yard manure. Khan *et al.* (2009) observed that plant height and leaf area of wheat significantly increased by combining organic and inorganic N fertilizers.

Leaf area index (LAI) in 2013 was relatively higher than in 2014 under all treatments (Table 4.11). This could result in higher light interception in 2013 which would allow good photosynthesis and production of assimilates. An increase from 8.9 – 44.0 % in LAI was observed in 2013 and 2014 respectively compared to the control when 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK were applied.

Generally, a high CGR resulting from high LAI tends to lead to high yield (Valero *et al.*, 2005). A strong correlation ($R^2 = 88$ %) was found between NAR and CGR as shown in Figure 4.12. Habib *et al.* (2012) reported that maximum maize leaf area, leaf area duration, crop growth rate and net assimilation rate resulted from combined application of inorganic fertilizer and poultry manure. Furthermore, Efthimiadou *et al.* (2010) obtained the highest plant height, dry weight, leaf area index and yield of sweet maize under cow manure treatments (with or without chemical fertilizer). According to Habib *et al.* (2012), high CGR contributed to high grain yield.

4.7.2.2 Effect of composted cattle manure and inorganic fertilizer on the yield of pearl millet and cowpea under strip cropping

Pearl millet grain yield under combined use of compost and NPK fertilizer was significantly different ($P < 0.001$) in 2013 indicating a synergistic effect of both amendments (Table 4.12). In 2014 grain yield interaction effect of compost and mineral fertilizer was not significant indicating only additive effect of these amendments. The highest pearl millet grain yields of 1762 and 866 kg ha^{-1} were recorded in 2013 and 2014 respectively under the application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK. These yields led to 133 and 71 % increases respectively over the control (Table 4.12). These results confirm the hypothesis of this study which stated that integrated use of composted cattle manure and mineral fertilizer under strip cropping systems results in high yield of pearl millet and efficient use of both amendments. However, the decline in grain yield observed under 5000 kg ha^{-1} compost application in both 2013 and 2014 cropping seasons, could be explain by the fact that slower nutrient release is important when relatively large quantities of organic amendment are applied at a time (Lehmann and Schroth, 2003).

According to Wu and Ma (2015), integrated nutrient management enhances crop yields by 8 – 150 % compared to conventional practices, increases water-use efficiency and also the economic returns of farmers, while improving soil health and its sustainability. Singh and Chauhan (2014) showed that combined application of 75 % NPK + 4 t ha^{-1} FYM increased grain yield of pearl millet by 109.3 % and stover yield by 121.2 % over control. In line with these results, Yamoah *et al.* (2002) found a synergetic effect under fertilizer and crop residues application (P_{FxCR} = 0.0001). Kapkiyai *et al.* (1998) reported that combined use of organic and inorganic nutrient sources resulted in synergy and improved synchronization of nutrient release and uptake by plants leading to higher yields. Abunyewa *et al.* (2007) also found in a three year study in northern Ghana 64 to 75 % in 1996, 59 to 69.5 % in 1997 and 43 to 66.8 % in 1998 increase in maize grain yield due to manure plus fertilizer over sole fertilizer application. Diangar *et al.* (2004) reported an increase of more than 40 % of millet yield under sole compost application compared to the control and an additional 10 % increase in millet yield was observed when compost was supplemented with rock phosphate. Furthermore, Badiane *et al.*

(2001) found millet grain yield of 1230 kg ha^{-1} under farmer‟s field using compost and NPK while it was only 430 kg ha^{-1} under farmer‟s field when neither compost nor fertilizer was applied in Senegal. In addition, Rezaei *et al.* (2014) reported that a combination of crop residues and mineral fertilizer resulted in higher pearl millet yields compared to sole application of crop residues or fertilizer in Niger.

Pearl millet straw yield (Table 4.13) responded positively to the combined use of compost and NPK fertilizer with the highest straw yields of 6750 kg ha^{-1} and 4750 kg ha^{-1} under application of 5000 kg ha^{-1} compost + 100 kg ha^{-1} NPK and 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK in 2013 and 2014 respectively. These highest straw yields gave increases of 92.8 % in 2013 and 209 % in 2014. Omae *et al.* (2014) found that manure increased total biomass by 127 to 147 % and millet grain yield by 130 to 184 % in the sahelian zone of Niger. The interaction of compost and mineral fertilizer was significant ($P = 0.05$ in 2013 and $P < 0.000$ in 2014) in both cropping years indicating a synergetic effect of both amendments. Buerkert *et al.* (2001a) demonstrated that the average total dry matter (TDM) yield in P placed plots was 672 kg ha^{-1}, which was 120 % higher than the average control plots. This result was confirmed by a second set onfarm test in 1999 where average yield increases of 118 % for NPK and 116 % for DAP were found. Fatondji *et al.* (2006) showed that increasing the rate of cattle manure application from 1 to 3 t ha^{-1} increased the yield by 115 % TDM, but increasing the manure application rate further from 3 to 5 t ha^{-1} only gave an additional 12 % yield increase.

The lowest cowpea grain and haulm yields in 2014 could be due to low rainfall received during the cropping period (Tables 4.14 and 4.15). This low rainfall (Figure 4.1) influenced the soil moisture and activities of microorganisms which affected the decomposition and nutrients availability of compost. Soon *et al.* (2001) reported that low and poorly distributed rainfall could have reduced the availability of nutrients to the maize plants. Soil moisture content influenced N mineralization and availability and subsequently maize growth and N uptake. The high yield increase over the control observed under all treatments in 2014 was due to the low yield of the control (49 kg ha^{-1}). Ghosh *et al.* (2004) showed that the use of 75 % of NPK + 5 t of farmyard manure improved the seed yield of soybean by 47 and 32 % over the use of 75 % of NPK in sole and intercropped systems respectively. The combined use of compost and mineral fertilizer in 2013 and 2014 cropping seasons had only additive effect on cowpea grain yield since the interaction was not significant. On the contrary, treatments had synergetic effect ($P < 0.001$) on cowpea haulm yield in 2013 as shown in Table 4.15.

4.8 Effect of composted cattle manure and inorganic fertilizer on rainfall use efficiency of pearl millet and cowpea under strip cropping

4.8.1 Results

Rainfall use efficiency (RUE) of pearl millet and cowpea following the sole and combined use of compost and mineral fertilizer are presented in Table 4.16. Except under the application of 5000 kg ha^{-1} compost + 200 kg ha^{-1} NPK in 2014 for pearl millet, RUE was greater under all treatments in 2013 than in 2014 for both pearl millet and cowpea. Higher values of RUE ie. 2.83 and 2.37 kg mm^{-1} for pearl millet were recorded by applying 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK with in 2013 and 2014 respectively. Rainfall use efficiency of Pearl millet was significant under sole application of compost (P = 0.009 (2013), P < 0.001 (2014)) and sole mineral fertilizer (P < 0.001) in both 2013 and 2014, while the interaction was significant (P < 0.001) only in 2013. Rainfall use efficiency of cowpea was significant in 2013 and 2014 under sole compost application (P < 0.001, P = 0.003) and in 2013 under sole mineral fertilizer application only (P = 0.042).

Table 4.16: Rainfall use efficiency of pearl millet and cowpea

Treatments (kg ha^{-1})		Millet RUE (kg mm^{-1})		Cowpea RUE (kg ha^{-1})	
Compost	NPK/DAP fertilizer	2013	2014	2013	2014
0	0	1.22	0.97	0.21	0.13
	100/50	1.97	1.45	0.27	0.25
	175/75	1.84	1.40	0.29	0.24
	200/100	2.01	1.42	0.33	0.29
2500	0	2.46	1.39	0.48	0.25
	100/50	1.46	2.05	0.58	0.64
	175/75	2.84	2.28	0.49	0.54
	200/100	2.25	1.87	0.49	0.49
5000	0	1.19	0.91	0.36	0.36
	100/50	2.17	2.01	0.58	0.81
	175/75	2.79	2.37	0.36	1.04
	200/100	1.48	1.52	0.40	0.56
Fpr.					
Compost		0.009	< 0.001	< 0.001	0.003
Mineral Fertilizer		< 0.001	<.001	0.042	0.061
C x M.F		< 0.001	0.145	0.350	0.613

Lsd (0.05)				
Lsd $_{C}$	0.300	0.250	0.070	0.240
Lsd $_{M.F}$	0.350	0.290	0.080	0.280
Lsd $_{C \times M.F}$	0.610	0.510	0.150	0.480

NPK for Millet, DAP for Cowpea

4.8.2 Discussion

Rainfall use efficiencies (RUE) of pearl millet and cowpea were relatively higher in 2013 than in 2014 in all treatments (Table 4.16). This could be due to the fact that yield was higher in 2013 as a result of well distributed than in 2014. Rainfall use efficiency was particularly higher under combined use of compost and mineral fertilizer. Compost had significant effect ($P = 0.009$ (2013) and $P < 0.001$ (2014) for millet and $P < 0.001$ (2013) and $P = 0.003$ (2014) for cowpea) on RUE in both years for pearl millet and cowpea (Table 4.16). The application of 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK for millet gave a RUE of 2.79 and 2.37 kg mm^{-1} in 2013 and 2014 cropping seasons respectively. This could be explained by the improved soil structure and moisture storage resulting from compost application. In fact, RUE has been a surrogate for WUE in rainfed agriculture because soil management practices that increase soil water storage have a positive impact on WUE. Hatfield *et al.* (2001) reported that modifying nutrient management practices can increase water use efficiency (WUE) by 15 to 25 % and it is possible to increase WUE by 25 to 40 % through soil management practices that involve tillage. Furthermore, Fatondji *et al.* (2006) showed a high range of millet grain WUE

1.8 and 1.9 kg mm^{-1} and 2 and 2.1 kg mm^{-1} at Damara and Kakassi (Niger) in 1999 and 2000 respectively under manure application compared to straw application.

4.9 Pearl millet and cowpea harvest index under sole and combined application of compost and inorganic fertilizer

4.9.1 Results

Table 4.17 shows harvest indices (HI) of pearl millet and cowpea. The highest pearl millet HI (45.3 %) was recorded by applying 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK in 2014, but generally millet HI was higher in 2013 than in 2014. Both pearl millet and cowpea harvest indices were significant under sole application of compost and mineral fertilizer in 2013 and 2014 (Table 4.17). The interaction was only significant (P = 0.009) for pearl millet in 2014 cropping season under combined application of compost and mineral fertilizer. On the other hand, cowpea HI was generally higher in 2014 than in 2013. The highest cowpea HI values of 90.5 (2013) and 115.4 % (2014) were obtained by applying 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP and 5000 kg ha^{-1} compost + 50 kg ha^{-1} DAP respectively.

Table 4.17: Harvest index of pearl millet and cowpea under sole and combined use of compost and mineral fertilizer

Treatments (kg ha^{-1})		Harvest index (%)			
		Millet		Cowpea	
Compost	NPK/DAP fertilizer	2013	2014	2013	2014
0	0	21.8	23.6	30.3	53.4
	100/50	24.5	25.3	39.0	62.0
	175/75	29.7	28.6	44.0	73.6
	200/100	23.8	15.4	42.5	54.9

2500	0	42.3	18.3	45.1	41.4
	100/50	20.4	18.6	90.5	75.5
	175/75	40.4	18.1	43.5	66.3
	200/100	34.5	17.7	67.8	67.9
5000	0	20.4	15.1	51.7	61.5
	100/50	20.2	34.0	67.9	115.4
	175/75	40.0	45.3	42.3	85.9
	200/100	20.5	22.0	52.8	96.5
Fpr.					
Compost		0.044	0.001	0.001	0.006
Mineral Fertilizer		0.027	0.002	0.004	0.033
C x M.F		0.269	0.009	0.068	0.584
Lsd (0.05)					
Lsd $_{C}$		8.290	5.410	11.330	18.480
Lsd $_{M.F}$		9.570	6.250	13.090	21.340
Lsd $_{C\ x\ M.F}$		16.570	10.830	22.660	36.960

NPK for Millet, DAP for Cowpea, C = compost, M.F = mineral fertilizer

4.9.2 Discussion

The HI, according to Smith and Hamel (2012) usually refers to the proportion of the total dry weight biomass (grain/biomass) in the harvest organs or the ability to mobilize photosynthates from stover (pod, straw) to seed (Polania *et al.*, 2015). Pearl millet and cowpea HI were significantly (P = 0.001 and P = 0.002 for millet and P = 0.001 and P = 0.004 for cowpea) affected under sole application of compost and mineral fertilizer in both cropping years (Table 4.17). Highest pearl millet and cowpea HI were obtained generally under combined use of compost and mineral fertilizer. Sinclair and Weiss (2010) reported that significant improvement in yield of new varieties has been attributed to the increases in HI. The higher values of cowpea HI observed in 2014 could be due to the lower haulm production as a consequence of low rainfall (Figure 4.1) particularly forward the end of the cropping season.

4.10 Nitrogen and phosphorus use efficiency of pearl millet and cowpea as affected by compost and mineral fertilizer use

4.10.1 Results

Nitrogen and phosphorus use efficiencies of pearl millet and cowpea were calculated for sole and combined use of compost and mineral fertilizer. Nitrogen use efficiency (NUE) of pearl millet NUE was relatively higher in 2013 than in 2014 under all treatments. The highest NUE of 125.2 kg kg^{-1} was obtained under the application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK in 2013. However, in 2014 cropping season, the highest NUE of 65.8 kg kg^{-1} was recorded under the application of 175 kg ha^{-1} NPK. Highest values for phosphorus use efficiency (PUE) of 454 and 353 kg kg^{-1} were recorded under the control in 2013 and 5000 kg ha^{-1} compost + 100 kg ha^{-1} NPK in 2014 (Table 4.18). On average, N and P use efficiencies for millet were increased by 60.2 % and 31.1 %, respectively with the application of compost at 2500 kg ha^{-1} + 175 kg ha^{-1} NPK over the control plots. The highest cowpea NUE of 33.7 kg kg^{-1} was obtained by applying 5000 kg ha^{-1} compost + 50 kg ha^{-1} DAP in 2014 cropping season. For cowpea PUE, the highest value of 197.9 was recorded under the application of 5000 kg ha^{-1} compost + 100 kg ha^{-1} DAP.

Table 4.18: Nitrogen and phosphorus use efficiencies of pearl millet and cowpea under various treatments

Treatments (kg ha^{-1})		Millet NUE		Millet PUE		Cowpea NUE	Cowpea PUE	
Compost	NPK/DAP fertilizer	2013	2014	2013	2014			
0	0	74.0	56.1	454.0	193.0	30.6	146.0	
	100/50	72.0	55.6	231.0	166.0	32.0	165.7	
	175/75	67.6	65.8	237.0	169.0	29.7	166.7	2014
			2014					
	200/100	77.2	55.3	212.0	218.0	25.0	168.5	
2500	0	76.0	61.0	314.0	235.0	31.7	169.6	
	100/50	70.7	54.8	230.0	232.0	33.0	164.1	
	175/75	125.2	57.4	253.0	253.0	30.6	160.9	
	200/100	74.6	60.0	239.0	252.0	31.5	165.1	
5000	0	78.2	56.5	292.0	236.0	29.5	155.9	
	100/50	74.2	55.0	393.0	353.0	33.7	161.8	
	175/75	70.9	59.9	183.0	212.0	32.4	152.8	
CV (%)						9.2	11.2	
Lsd (0.05)								
Lsd C		19.8	6.7	111.3	67.2	2.4	15.6	
Lsd M.F		22.9	7.7	128.5	77.5	2.8	18.0	
Lsd C x M.F		39.6	13.3	222.5	134.3	4.8	31.2	
	71.5	57.5	232.0	334.0				
200/100	30.1	13.6	48.2	33.4			32.7	197.9

NPK for Millet, DAP for Cowpea

4.10.2 Discussion

Nutrient use efficiency, defined as kilogramme of yield produced per kilogramme of nutrient uptake (Roberts, 2008), was calculated for pearl millet and cowpea. Higher N and P use efficiencies were recorded in 2013 than in 2014 (Table 4.18) particularly under combined use of compost and NPK fertilizer for pearl millet. This could be explained by the high amount of nutrients provided by the combined use of compost and mineral fertilizer, where nutrients availability were conditioned by moisture conservation and microbial activities due to compost application. These results were higher than the findings of Mosier *et al.* (2004) who found N use efficiencies of 11.7 and 20.3 kg kg^{-1} respectively for sorghum and wheat when N was used alone, but with P addition NUE increased from 17.1 to 25.9 kg kg^{-1} for the same crops. This indicated that nutrient use efficiency could be improved through combined use of soil amendments.

Cowpea N and P use efficiencies were generally high in 2014 (Table 4.18) due to low yield following the statement made by Roberts (2008) that nutrient use efficiency is high at a low yield level. This is because any small amount of nutrient applied could give a large yield response.

4.11 Nitrogen and phosphorus recovery of pearl millet and cowpea as affected by compost and mineral fertilizer use

4.11.1 Results

Total nitrogen and phosphorus recoveries of pearl millet (grain + straw) and cowpea (grain + haulm) are presented in Table 4.19. The treatments did not significantly affect % N and P recoveries for both pearl millet and cowpea even though they improved over the control. Higher values % N recovery of 68.9, 56.9 and 63.7 for pearl millet were found under application of 100, 200 kg ha^{-1} NPK and 2500 kg ha $^{-1}$ compost in 2013. In 2014, higher values of % N recovery of millet were found by applying 100 kg ha^{-1} NPK (82.3), 2500 kg ha^{-1} compost (71.9) and 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK (43.6).

At the same time, % P recovery values of 65.0, 48.9 and 16.1 for pearl millet were recorded under application of 100, 200 kg ha^{-1} NPK and 2500 kg ha^{-1} compost + 100 kg ha^{-1} NPK respectively in 2013. In 2014, applying 100, 175 and 200 kg ha^{-1} NPK resulted in the higher P recovery values of 20.2, 37.9 and 30.8 % respectively.

On the other hand, high cowpea % N recoveries were found under the application of 50 kg ha^{-1} (51.8 %), 2500 kg ha^{-1} compost (60.0 %) and 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP (27.2 %) in 2013. In 2014, higher recovery values of cowpea % N of 32.0, 35.2 and 33.3 were found under application of 50 kg ha^{-1} DAP, 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP and 5000 kg ha^{-1} compost + 75 kg ha^{-1} DAP respectively. For cowpea % P recoveries, higher values were found by applying 100 kg ha^{-1} DAP (3.1), 2500 kg ha^{-1} compost + 50 kg ha^{-1} (2.2) and 2500 kg ha^{-1} compost + 75 kg ha^{-1} DAP (2.4) in 2013. In 2014, higher values of cowpea % P recovery of 5.2, 3.9 and 2.7 % were obtained following the application of 50 kg ha^{-1} DAP, 100 kg ha^{-1} DAP and 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP as presented in Table 4.19.

Table 4.19: Nitrogen and phosphorus recoveries of pearl millet and cowpea under sole and combined use of compost and mineral fertilizer

Treatments (kg ha^{-1})		Millet % N recovery		Millet % P recovery		Cowpea % N recovery		Cowpea % P recovery	
Compost	NPK/DAP fertilizer	2013	2014	2013	2014	2013	2014	2013	2014
0	100/50	68.9	82.3	65.0	20.2	51.8	32.0	1.0	5.2
	175/75	21.9	12.4	13.5	37.9	12.9	13.8	0.8	2.2
	200/100	56.9	21.5	48.9	30.8	20.4	31.2	3.1	3.9
2500	0	63.7	71.9	6.5	2.1	60.5	18.8	2.2	0.5

	100/50	13.8	29.7	16.1	8.8	27.2	35.2	1.5	2.7
	175/75	23.2	43.6	7.8	9.4	22.3	25.6	2.4	1.9
	200/100	19.4	20.9	4.6	8.5	9.7	12.6	1.3	1.4
5000	0	1.4	6.4	0.1	1.2	4.0	12.0	0.5	0.7
	100/50	35.6	7.5	3.0	0.9	12.4	17.3	1.0	1.4
	175/75	27.0	7.4	6.1	2.2	3.3	33.3	0.9	2.2
	200/100	27.1	20.2	8.0	2.8	0.4	11.8	0.5	0.8
CV (%)		106.0	159.7	202.3	116.7	76.0	70.0	84.0	67.1
Lsd (0.05)									
Lsd C		29.4	32.3	26.7	10.3	24.0	12.6	0.9	1.1
Lsd M.F		34.0	37.2	30.8	11.9	27.7	14.5	1.1	1.3
Lsd C x M.F		58.9	64.5	53.4	20.6	47.9	25.1	1.9	2.3

NPK for millet, DAP for cowpea

4.11.2 Discussion

Nutrient recovery refers to kilogrammes of nutrient uptake by crop per kilogramme nutrient applied. Nutrient recoveries were calculated following compost and mineral fertilizer application. Highest N and P recoveries (Table 4.19) were found under sole application of mineral fertilizer in both years for pearl millet and cowpea. This could be explained by the direct availability of nutrients in mineral fertilizer compared to the compost which has to undergo decomposition. Fofana *et al.* (2008) showed that average apparent recoveries of fertilizer applied P across years and treatments were significantly higher under infield (31 %) compared to outfield (18 %) conditions due to manure application on the infield. Low N and P recoveries were found under the application of 5000 kg ha^{-1} of compost which could be explained by the fact that nutrient availability under compost application was not direct and depended on factors conditioning the mineralization of compost. A review of best available information made by Roberts (2008) showed that average N recovery efficiency for fields managed by farmers ranges from about 20 to 30 % under rainfed conditions. Furthermore, Ladha *et al.* (2005) based on a worldwide data on N use efficiency for cereal crops from researcher-managed experimental plots reported that single-year fertilizer N recovery efficiencies averaged 65 % for corn, 57 % for wheat, and 46 % for rice.

4.12 Evaluation of the sustainability index and the agronomic efficiency of compost and mineral fertilizer under strip cropping.

4.12.1 Results

4.12.1.1 Evaluation of the sustainability index of compost and mineral fertilizer under strip cropping system.

Sustainability yield index (SYI) of both pearl millet and cowpea are presented in Table 4.20. Sustainability yield indices for both millet and cowpea were significantly different (P = 0.015 and 0.023) in 2013 and 2014 under sole application of mineral fertilizer. Sole application of compost had significant effect ($P < 0.001$) on cowpea only in 2014 cropping season. The higher pearl millet SYI values of 0.65 and 0.64 were found by applying 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK respectively in both years. Higher cowpea SYI values of 0.63 and 0.57 were recorded following the application of 5000 kg ha^{-1} compost + 50 kg ha^{-1} DAP and 5000 kg ha^{-1} of compost + 75 kg ha^{-1} DAP respectively in both cropping seasons.

Table 4.20: Pearl millet and cowpea sustainability yield index under compost and mineral fertilizer use during 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})		Sustainability yield index	
Compost	DAP fertilizer	Millet	Cowpea
0	0	0.22	0.00
	100/50	0.40	0.12
	175/75	0.38	0.12
	200/100	0.41	0.18
2500	0	0.48	0.29
	100/50	0.38	0.55
	175/75	0.64	0.43
	200/100	0.50	0.41
5000	0	0.21	0.24
	100/50	0.50	0.63
	175/75	0.65	0.57
	200/100	0.32	0.36
Fpr.			
Compost (C)		0.081	< 0.001
Lin.		0.300	< 0.001
Quad.		0.046	0.032
M.Fertilizer (M.F)		0.015	0.023
Lin.		0.065	0.184
Quad.		0.014	0.011
C x M.F		0.192	0.687
Lin.		0.952	0.746
Quad.		0.132	0.876

NPK for millet, DAP for cowpea

4.12.1.2 Agronomic efficiency of pearl millet and cowpea under combined application compost and mineral fertilizer

Higher pearl millet agronomic efficiency (AE) values of 5.21 and 1.82 kg kg^{-1} were obtained following the application of 100 kg ha^{-1} NPK in 2013 and 2014 respectively (Table 4.21). Pearl millet agronomic efficiencies were significantly influenced ($P < 0.001$ for sole compost and NPK and their interaction) by the treatments during 2013 and 2014 cropping seasons. Higher cowpea AE values of 0.46 and 0.47 kg kg^{-1} were obtained under the sole application of 50 kg ha^{-1} DAP in 2013 and 2014 cropping seasons respectively. Cowpea agronomic efficiencies were significant ($P < 0.001$ for sole compost and DAP) in both 2013 and 2014 cropping seasons. The interaction was significant ($P < 0.001$) only in 2014 cropping season.

Table 4.21: Pearl millet and cowpea agronomic efficiency as affected by treatments

Treatments (kg ha^{-1})		Millet AE (kg kg^{-1})		Cowpea AE (kg kg^{-1})	
Compost	NPK/DAP fertilizer	2013	2014	2013	2014
0	100/50	5.21	1.82	0.46	0.47
	175/75	2.51	0.93	0.30	0.25
	200/100	2.71	0.85	0.40	0.31
2500	0	0.33	0.07	0.07	0.02
	100/50	0.08	0.16	0.09	0.08
	175/75	0.40	0.19	0.07	0.06
	200/100	0.26	0.13	0.07	0.05
5000	0	0.01	0.00	0.02	0.02
	100/50	0.13	0.08	0.05	0.05

175/75	0.20	0.10	0.02	0.07
200/100	0.04	0.04	0.02	0.03
Fpr.				
Compost (C)	< 0.001	< 0.001	< 0.001	< 0.001
Lin.	< 0.001	< 0.001	< 0.001	< 0.001
Quad.	< 0.001	< 0.001	0.073	< 0.001
M.Fertilizer (M.F)	< 0.001	< 0.001	0.055	< 0.001
Lin.	0.007	0.038	0.096	0.038
Quad.	< 0.001	< 0.001	0.119	< 0.001
C x M.F	< 0.001	< 0.001	0.06	< 0.001
Lin.	0.003	0.057	0.033	0.057
Quad.	< 0.001	0.007	0.348	0.007

4.12.2 Discussion

4.12.2.1 Evaluation of the sustainability index of compost and mineral fertilizer under strip cropping system

In dry sahelian conditions where rainfall is an important component affecting crop yield, it is important to evaluate the sustainability of any practice. Thus pearl millet and cowpea sustainability yield index (SYI) were calculated under combined use of compost and mineral fertilizer (Table 4.20). Pearl millet and cowpea SYI were significant (P = 0.01 and 0.02) during both years, with the highest SYI values of 0.65 and 0.63 obtained following the application of 5000 kg ha^{-1} of compost + 175 kg ha^{-1} NPK and 5000 kg ha^{-1} of compost + 50 kg ha^{-1} DAP respectively. Efthimiadou *et al.* (2010) concluded from the SYI data that maize crop is more stable under double rate of cow manure and combined organic and inorganic fertilizer treatment as compared with inorganic fertilizer application. In addition, Vittal *et al.* (2002) stated that any practice with SYI > 0.66 is considered as a recommendable component for production of a crop in a region and SYI of 0.50 to 0.65 is considered as highly promising, while a practice with SYI < 0.33 is undependable. It can thus be said that the application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 5000 kg ha^{-1} of compost + 175 kg ha^{-1} NPK are the most highly promising treatments for pearl millet production. For cowpea, combined use of 5000 kg ha^{-1} compost + 50 kg ha^{-1} DAP and 5000 kg ha^{-1} compost + 75 kg ha^{-1} DAP are the most promising treatments. This shows that integrated use of compost and mineral fertilizer is more sustainable than sole application of each confirming again the hypothesis of this study.

4.12.2.2 Agronomic efficiency of pearl millet and cowpea under sole and integrated application of compost and mineral fertilizer

Pearl millet and cowpea AE were high under sole application of mineral fertilizer as shown in Table 4.21. These results are in line with the findings of Efthimiadou *et al.* (2010) who found that AE was greater in plots treated with mineral fertilizer. This could be explained by the direct availability and uptake of nutrients in mineral fertilizer. Under combined use of compost and mineral fertilizer, application of 2500 kg ha^{-1} of compost + 175 kg ha^{-1} NPK recorded the highest pearl millet AE values of 0.4 and 0.19 kg kg^{-1} in 2013 and 2014 respectively in 2013 and 2014. The highest cowpea AE values of 0.09 and 0.08 kg kg^{-1} were recorded under combined use of 2500 kg ha^{-1} of compost + 50 kg ha^{-1} DAP. Fatondji *et al.* (2006) found N, P and K agronomic efficiencies for pearl millet as 33, 118 and 57 kg kg^{-1} respectively under the application 1000 kg ha^{-1} of manure which decreased with the increase of manure rate. The lower AE recorded and combined used of compost and mineral fertilizer for both millet and cowpea could be explain by the high rate of amendment application. Vanlauwe *et al.* (2011) reported that AE is low for excessive inorganic and organic fertilizer application.

4.13 Economic evaluation of composted cattle manure and mineral fertilizer under strip cropping

4.13.1 Results

To evaluate the economic effect of integrated use of compost and mineral fertilizer on pearl millet and cowpea under strip cropping system, cost involved in each treatment was calculated (Table 4.22). To calculate the price of grain yield of pearl millet and cowpea, the mean market price of a "tiya", local unit of measure which is equivalent to 2.5 kg was used. The "tiya" costed respectively 400 FCFA in November and 750 FCFA in June for pearl millet and 1,250 FCFA and 1,500 FCFA for cowpea. The mean price of a "tiya" was 575 FCFA or US $ 1.15 for pearl millet and 1375 FCFA or US $ 2.75 for cowpea. So 1 kg each of pearl millet and cowpea grains costed 230 FCFA (US $ 0.46) and 550 FCFA (US $ 1.10) respectively.

Table 4.22: Parameters used to calculate the economic returns under the different treatments

Quantity (kg ha^{-1})		Price in CFA*		Price in dollar (US $)*	
NPK + Compost	DAP + compost	NPK + Compost	DAP + compost	NPK + Compost	DAP + compost
-	-	-	-	-	-
100	50	34,000	17,000	68	34
175	75	59,500	25,500	119	51

200	100	68,000	34,000	136	68
2500	2500	162,500	162,500	325	325
2600	2550	196,500	179,500	393	359
2675	2575	222,000	188,000	444	376
2700	2600	230,500	196,500	461	393
5000	5000	325,000	325,000	650	650
5100	5050	359,000	369,000	718	738
5175	5075	384,500	350,500	769	701
5200	5100	393,000	359,000	786	718

*The exchange rate used is: 500 FCFA = US $1

4.13.1.1 Cost and economic returns of combined application of compost and mineral fertilizer

Net return (NR) and relative increase in income (RII) of pearl millet were significantly (P < 0.001) affected by the sole application of compost and mineral fertilizer in both cropping years. The compost and NPK fertilizer interaction affected significantly (P < 0.001) pearl millet NR and RRI only in 2013 cropping season. The highest pearl millet NR and RII values of US $ 495.5 (2013) and 306.4 % (2014) were obtained under sole application of NPK fertilizer in both years. Among all the combined use of compost and NPK fertilizer, application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK recorded the highest relative income of 233.8 % in 2013 with a net return of US $ 366.3 for pearl millet. Combined application of 2500 kg ha^{-1} compost and NPK at 100, 175 and 200 kg ha^{-1} gave positive net returns in 2013 only. In 2014, only the addition of mineral fertilizer had a positive millet net return.

Table 4.23: Net return and relative increase in income of pearl millet under sole and combined use of compost and mineral fertilizer

Treatments (kg ha^{-1})		Millet Net return ($)		Millet RII (%)	
Compost	NPK/DAP fertilizer	2013	2014	2013	2014
0	0	-	-	-	-
	100	495.5	182.2	162.9	150.9
	175	407.0	122.4	152.0	183.4
	200	437.3	108.8	165.3	190.1
2500	0	377.3	-83.7	200.8	187.2
	100	23.3	-40.0	120.1	265.7
	175	366.3	-50.1	233.8	306.4
	200	180.9	-139.1	187.1	250.3
5000	0	-310.8	-492.9	97.8	138.5
	100	-98.4	-371.2	179.6	254.9
	175	27.5	-359.4	229.5	299.5
	200	-363.6	-523.7	122.1	210.4
Fpr.					
Compost (C)		< 0.001	< 0.001	< 0.001	< 0.001
Linear		< 0.001	< 0.001	0.006	< 0.001
Quadratic		< 0.001	< 0.001	< 0.001	< 0.001
Mineral Fertilizer (M.F)		< 0.001	< 0.001	< 0.001	< 0.001
Linear		0.051	0.968	< 0.001	< 0.001
Quadratic		< 0.001	< 0.001	< 0.001	< 0.001
C x M.F		< 0.001	0.082	< 0.001	0.249
Linear		0.003	0.084	0.003	0.049
Quadratic		< 0.001	0.160	< 0.001	0.535

Cowpea net return (NR) and relative increase in income (RII) resulting from sole and combined application of mineral fertilizer (DAP) and compost are presented in Table 4.24. Significant differences ($P < 0.001$) for cowpea NR and RII were observed under the sole application of compost in both cropping seasons. The highest cowpea net return of US

$155.3 resulting in a relative income of 160.6 % was obtained by applying 100 kg ha^{-1} of DAP fertilizer in 2013. Among all the combined use of compost and DAP fertilizer, only the application of 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP had a positive net return (US $ 37.5) in 2013 while in 2014, all the interactions had a negative net return. On the other hand, cowpea NR and RII were significant (P = 0.04 and 0.001) under sole application of DAP fertilizer in 2013 while the combined use of compost and DAP fertilizer had significant effect (P = 0.036) only on the cowpea RII in 2013.

Table 4.24: Cowpea net return and relative increase in income under combined use of compost and mineral fertilizer

Treatments (kg ha^{-1})		Cowpea Net return ($)		Cowpea RII (%)	
Compost	NPK/DAP fertilizer	2013	2014	2013	2014
0	0	-	-	-	-
	50	152.6	69.9	135.4	192.0
	75	143.7	48.6	138.0	183.0
	100	155.3	52.1	160.6	232.0
2500	0	3.9	-220.8	236.5	198.0
	50	37.6	-93.2	288.3	532.0
	75	-39.8	-155.1	238.7	392.0
	100	-59.2	-189.8	239.7	403.0
5000	0	-407.5	-500.3	173.2	294.0
	50	-342.6	-401.9	284.5	678.0
	75	-453.5	-272.6	174.6	758.0
	100	-447.8	-488.5	191.6	491.0
Fpr.					
Compost (C)		< 0.001	< 0.001	< 0.001	< 0.001
Linear		< 0.001	< 0.001	< 0.001	< 0.001
Quadratic		< 0.001	0.606	< 0.001	0.69
Mineral Fertilizer (M.F)		0.044	0.161	0.001	0.013

Linear	0.883	0.539	0.065	0.046
Quadratic	0.054	0.032	0.009	0.009
C x M.F	0.064	0.686	0.036	0.724
Linear	0.006	0.946	0.003	0.98
Quadratic	0.598	0.869	0.415	0.794

4.13.1.2 Estimation of value cost ratio for pearl millet and cowpea under sole and integrated use of compost and mineral fertilizer

The profit in pearl millet resulting from the sole and combined application of composted cattle manure and NPK mineral fertilizer in 2013 and 2014 cropping season were appraised by the value cost ratio (VCR) as presented in Table 4.25 The sole application of NPK mineral fertilizer provided a net positive profit in both 2013 and 2014 cropping seasons since their VCR was higher than 1. However, 2500 kg ha^{-1} compost gave a net positive profit only in 2013 with a VCR of 2.2. In 2013, VCR values of 1.1, 1.8, 1.4 and 1.0 were found under combined use of 2500 kg ha^{-1} compost with 100, 175 and 200 kg ha^{-1} NPK mineral fertilizer respectively (Table 4.25). The VCR values observed is an indication of a net positive profit of the combined use of compost and mineral fertilizer. Application of sole compost and NPK mineral fertilizer and their interaction had significant effect ($P < 0.001$) on the VCR of pearl millet.

On the other hand, cowpea VCR values were generally higher in all treatments in 2013 than 2014 (Table 4.25). Application of sole DAP mineral fertilizer provided a net positive return in 2013 and 2014 cropping seasons since their VCR values were greater than 1. In 2013, only combined use of 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP gave a positive cowpea net profit with VCR of 1.1. The sole application of 2500 kg ha^{-1} of compost gave a positive profit VCR (1.0). In 2014 cropping season, only DAP mineral fertilizer had net positive profit even though treatments significantly ($P < 0.001$) affected the VCR.

Table 4.25: Value cost ratio of sole and combined use of compost and mineral fertilizer

Treatments (kg ha^{-1})		Millet VCR		Cowpea VCR	
Compost	DAP fertilizer	2013	2014	2013	2014
0	100/50	8.3	3.7	5.5	3.1
	175/75	4.4	2.0	3.8	2.0
	200/100	4.2	1.8	3.3	1.8
2500	0	2.2	0.7	1.0	0.3
	100/50	1.1	0.9	1.1	0.7
	175/75	1.8	0.9	0.9	0.6
	200/100	1.4	0.7	0.9	0.5
5000	0	0.5	0.2	0.4	0.2
	100/50	0.9	0.5	0.5	0.5
	175/75	1.0	0.5	0.4	0.6
	200/100	0.5	0.3	0.4	0.3
Fpr.					
Compost (C)		< 0.001	< 0.001	< 0.001	< 0.001
Linear		< 0.001	< 0.001	< 0.001	< 0.001
Quadratic		< 0.001	< 0.001	< 0.001	< 0.001
M.Fertilizer (M.F)		< 0.001	< 0.001	< 0.001	< 0.001
Linear		< 0.001	< 0.001	< 0.001	0.026
Quadratic		< 0.001	< 0.001	< 0.001	< 0.001
C x M.F		< 0.001	< 0.001	< 0.001	< 0.001
Linear		< 0.001	< 0.001	< 0.001	0.040
Quadratic		< 0.001	< 0.001	< 0.001	0.050

NPK for millet, DAP for cowpea

4.13.2 Discussion

4.13.2.1 Net return, relative increase in income and value cost ratio of compost and mineral fertilizer

The profit derived from any technology is a key entry point for its adoption by farmers, particularly the short-term cost-benefit as reported by De Jager *et al.* (1998). Net return (NR) and relative increase in income (RII) derived from sole and combined use of composted cattle manure and mineral fertilizer were evaluated. Significant differences ($P < 0.001$) were found for NR and RII for both pearl millet and cowpea in both years after sole application of compost and mineral fertilizer (Tables 4.23 and 4.24). The interaction affected significantly ($P < 0.001$) NR and RII for pearl millet in 2013 while, RII for cowpea was significant ($P = 0.036$) during the 2013 cropping season. Pearl millet and cowpea gave the highest NR and RII under sole application of mineral fertilizer in both cropping years. Under combined use of compost and NPK mineral fertilizer for pearl millet production, the sole application of 100 kg ha^{-1} NPK mineral fertilizer gave the highest NR of US $ 495.5 leading to 162.9 % relative increase in income. Among the combined application of compost and NPK mineral fertilizer, the use of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK gave the highest NR of US $ 366.3 leading to a RII of 233.8 %. This combination recorded also a VCR of 1.8 in 2013. Zhen and Routray (2003) reported that a farming enterprise satisfies conditions for economic sustainabilty when the VCR is greater than one (1).

Cowpea production recorded the highest NR of US $ 155.3 leading to 160.6 % RII under sole application of 100 kg ha^{-1} of DAP mineral fertilizer. Among the combined use of compost and DAP mineral fertilizer, the application 2500 kg ha^{-1} of compost + 50 kg ha^{-1} DAP yielded the highest NR of US $ 37.5 with a VCR of 1.1 in 2013. These findings for pearl millet and cowpea under combined use of compost and mineral fertilizer were in line with the findings of Mucheru-Muna *et al.* (2007) who obtained the highest maize net benefit of US $ 938.8 with a benefit cost ratio (BCR) of 2.5 under application of manure with half recommended rate of inorganic fertilizer. Kiani *et al.* (2005), found a wheat net return of Roupies (Rs.) 1776 with a VCR of 8.39 and RII of
20.20 with a variable cost of Rs. 1260 which a farmer can easily afford under the application of 1/2 N and 1/2 FYM in Pakistan. Furthermore, under cotton cash crop production in Pakistan, Khaliq *et al.* (2006) found that, addition of full recommended NPK fertilizer with effective microorganisms (EM) + organic materials (OM) increased net return by US $ 350, which represented 129 % increase in net income with a VCR of 4.05. During the 2014 cropping season, results of this study showed that application of sole compost and its combined use with NPK gave negative NR which could be explained by the low nutrients released from compost compared to 2013 especially NPK
(Figure 4.5) and also low recorded rainfall (Figure 4.1) particularly at maturity stage. Soon *et al.* (2001) demonstrated that low and poorly distributed rainfall can reduce the availability of nutrients to maize plant and its N uptake. This may have resulted in the low grain yield of pearl millet which induced the negative NR.

The higher VCR and NR for pearl millet and cowpea (Tables 4.23, 4.24 and 4.25) were recorded under sole application of mineral fertilizer in both years. This is contrary to the findings of Mucheru-Muna *et al.* (2007) who reported a high BCR of 2.9 under sole application of manure. The application of 2500 kg ha^{-1} of compost recorded VCR of 2.1 and 1.0 for pearl millet and cowpea respectively in 2013. Mehmood *et al.* (2011) found a benefit cost ratio of organic wheat production of 1:1.08 (0.92) which was higher than inorganic wheat production having the value of 1:1.01(0.99).

4.14 Quantification of added benefits of pearl millet and cowpea under integrated use of compost and mineral fertilizer.

4.14.1 Results

Added benefit is defined as a result of positive interactions between organic resources and mineral fertilizer. The changes in pearl millet grain yield resulting from the interaction of composted cattle manure and NPK mineral fertilizer are shown in Figure 4.13. In 2014, all the interactions gave positive added benefit. However in 2013, positive added benefits were obtained under the combined application of 5000 kg ha^{-1} compost + 100 kg ha^{-1} NPK and 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK mineral fertilizer. Combined use of 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK recorded the highest positive added benefits of 606 and 386 kg ha^{-1} of grain in 2013 and 2014 cropping seasons respectively.

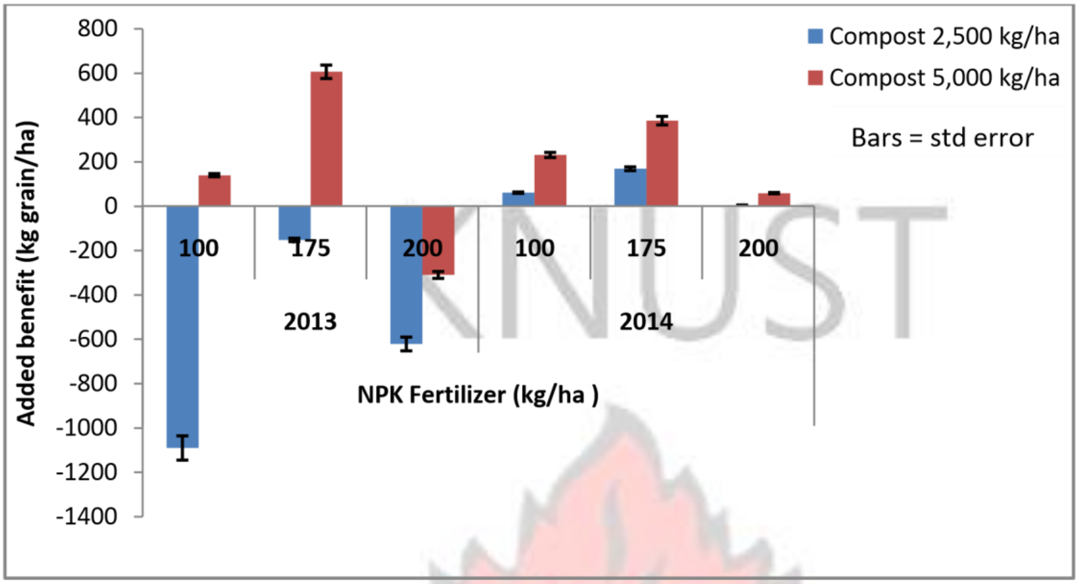

Figure 4.13: Added benefit of grain yield of pearl millet under integrated use of compost and NPK mineral fertilizer

Added benefit of cowpea grain yield resulting from integrated use of composted cattle manure and DAP mineral fertilizer is presented in Figure 4.14. All compost and DAP interactions in 2014 gave positive added benefits of cowpea grain yield. However in 2013, only the application of 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP and 5000 kg ha^{-1} compost + 50 kg ha^{-1} DAP gave positive added benefit. The highest added benefit of 211 and 97 kg ha^{-1} were obtained by applying 5000 kg ha^{-1} compost + 75 kg ha^{-1} DAP and 5000 kg ha^{-1} compost + 50 kg ha^{-1} DAP mineral fertilizer in 2014 and 2013 respectively.

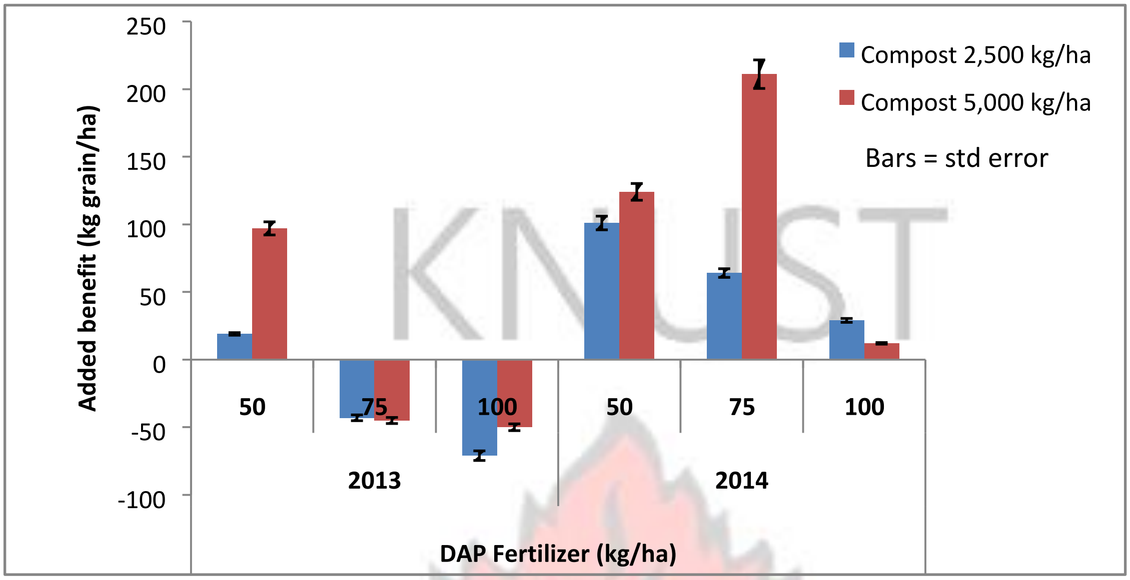

Figure 4.14: Added benefit of cowpea grain yield under integrated use of compost and DAP mineral fertilizer

4.14.2 Discussion

Added benefits, defined as a result of positive interactions between organic resources and mineral fertilizer (Vanlauwe *et al.*, 2002) were evaluated under combined use of compost and mineral fertilizer for pearl millet and cowpea during the two cropping seasons (2013 and 2014). Positive added benefit of pearl millet was recorded in all combined use of compost and NPK mineral fertilizer in 2014 (Figure 4.13). High added benefit values of 169, 231 and 386 kg ha^{-1} for pearl millet were found under the applications of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK, 5000 kg ha^{-1} compost + 100 kg ha^{-1} and 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK respectively in 2014. However in 2013, the application of 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK recorded high added benefit values of 140 kg ha^{-1} and 606 kg ha^{-1} for pearl millet. This could be explained by the higher rainfall use efficiency recorded in these treatments (Table 4.16). Vanlauwe *et al.* (2001) reported that benefits generated in mixed treatments were likely caused by improved soil water conditions compared with sole applications especially during drought period. These findings were different from the findings of Opoku (2011), who did not find any significant interactive effect from combined NPK fertilizer and manure at Maradi (Niger) and hence did not estimate added benefits or losses from this combination. However Opoku (2011), demonstrated that application of 100 % recommended rate of NPK and 5 t ha^{-1} of manure recorded the highest added benefits of 684 kg ha^{-1} at Sarauniya (Nigeria). In addition, Nhamo (2001) found added benefits of maize grain yield ranging from 663 to 1188 kg grain ha^{-1} and attributed the synergetic effect to the supply of cations by the manure to ameliorate the low cation content of the soil. Furthermore, Vanlauwe *et al.* (2001) found added benefits in terms of extra maize grain yield generated from the combined use of organic and urea inputs averaged from 490 to 580 kg ha^{-1} in Sékou

(Benin) and Glidji (Togo) respectively. Unlike pearl millet, all compost and mineral fertilizer (DAP) interactions in 2014 gave positive added benefit for cowpea grain yield. On the contrary in 2013, only the combined application of 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP and 5000 kg ha^{-1} compost + 50 kg ha^{-1} DAP gave a positive added benefit as shown in Figure 4.14.

4.15 Evaluation of nitrogen and phosphorus partial balance of sole and combined application of composted cattle manure and mineral fertilizer under strip cropping

4.15.1 Results

4.15.1.1 Nitrogen and phosphorus input and pearl millet output (uptake) in grain and straw

The nitrogen and phosphorus input (compost + NPK) on pearl millet and output (grain + straw) under sole and combined use of compost and mineral fertilizer are presented in Table 4.26. Pearl millet N output was significant ($P_{C \times MF}$ = 0.027) under combined use of compost and NPK fertilizer only in 2013 cropping season. Nitrogen output was generally higher in 2013 than 2014 under all treatments except under the application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK. In both years, the higher N output values of 46.4 (2013) and 38.6 (2014) kg ha^{-1} were obtained under the application of 5000 kg ha^{-1} compost + 100 kg ha^{-1} NPK and 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK mineral fertilizer respectively.

On the other hand, pearl millet phosphorus output was significant (P_C = 0.021 and P_{MF} = 0.027) under the sole applications of compost and NPK fertilizer in 2014 cropping season (Table 4.26). The higher pearl millet phosphorus output values of 17.9 and 15.3 kg ha^{-1} were obtained under the applications of 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK mineral fertilizer respectively in 2013 and 2014 cropping seasons.

Table 4.26: Nitrogen and phosphorus input and pearl millet output (uptake) during the 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})		N input (kg ha^{-1})		P input (kg ha^{-1})		N output (kg ha^{-1})		P output (kg ha^{-1})	
Compost	NPK fertilizer	2013	2014	2013	2014	2013	2014	2013	2014
0	0	0.0	0.0	0.0	0.0	23.3	16.2	8.1	6.6
	100	15.0	15.0	6.6	6.6	33.6	28.6	12.3	8.5
	175	26.3	26.3	11.5	11.5	29.0	13.0	9.6	11.5
	200	30.0	30.0	13.1	13.1	40.3	22.7	14.5	11.2
2500	0	25.5	30.5	75.3	80.8	39.2	34.2	12.9	8.8
	100	40.5	45.5	81.8	87.3	28.8	28.1	21.2	14.3
	175	51.8	56.8	86.7	92.2	35.1	38.6	14.8	15.3
	200	55.5	60.5	88.3	93.8	33.9	27.7	12.1	14.7
5000	0	51.0	61.0	150.5	161.5	24.0	13.0	7.8	8.9
	100	66.0	76.0	157.1	168.1	46.4	21.1	12.7	8.7
	175	77.3	87.3	162.0	173.0	43.8	21.9	17.9	10.8
	200	81.0	91.0	163.6	174.6	30.6	32.4	12.1	11.8
Fpr.									
Compost C						0.423	0.06	0.27	0.021
Mineral fertilizer (M.F)						0.24	0.731	0.249	0.027
C x M.F						0.027	0.388	0.493	0.824

4.15.1.2 Pearl millet nitrogen and phosphorus partial balance

Combined application of compost and mineral fertilizer led to an accumulation of N and P in the soil which resulted in positive partial N and P balances. Pearl millet N and P partial balances were significantly different (ie. $P < 0.001$ for N and P under sole compost) under the sole application of composted cattle manure and NPK mineral fertilizer in 2013 and 2014 cropping seasons. Negative N partial balances were recorded under control, the sole application of 2500 kg ha^{-1} compost and also sole application NPK mineral fertilizer in 2013 (Table 4.27). In 2014 cropping season, N partial balances were negative under the control, the sole applications of 2500 kg ha^{-1} compost and 100 kg ha^{-1} NPK fertilizer. Compost and NPK mineral fertilizer interaction had significant effect (P = 0.027) on N partial balance only in 2013 cropping season. Higher values of positive N partial balance of 50.4 and 58.6 kg ha^{-1} were obtained with the application of 5000 kg ha^{-1} compost + 200 kg ha^{-1} NPK mineral fertilizer during 2013 and 2014 cropping season.

Negative P partial balances were found under control (- 5.0 and - 4.3 kg ha^{-1}) and sole application of 100 kg ha^{-1} NPK (- 8.0 and – 6.6 kg ha^{-1}) in 2013 and 2014 cropping seasons. In addition, negative P partial balances of – 5.8 and – 2.0 kg ha^{-1} were recorded under the sole application of 100 kg ha^{-1} NPK fertilizer in 2013 and 2014 respectively. Higher positive values of P partial balances were obtained under combined use of compost and NPK fertilizer especially the application of 5000 kg ha^{-1} + 200 kg ha^{-1} NPK with values of 151.5 and 162.8 kg ha^{-1} respectively in 2013 and 2014 cropping seasons.

Table 4.27: Pearl millet nitrogen and phosphorus partial balance in 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})		N balance (kg ha^{-1})		P balance (kg ha^{-1})	
Compost	NPK fertilizer	2013	2014	2013	2014
0	0	-23.3	-16.2	-8.0	-6.6
	100	-18.6	-13.6	-5.8	-2.0
	175	-2.8	13.3	1.9	-0.1
	200	-10.3	7.3	-1.4	1.9
2500	0	-13.7	-3.7	62.3	72.0
	100	11.7	17.4	60.6	73.0
	175	16.6	18.2	71.9	76.9

	200	21.6	32.8	76.3	79.2
5000	0	27.0	48.0	142.7	152.6
	100	19.6	54.9	144.3	159.4
	175	33.4	65.4	144.1	162.2
	200	50.4	58.6	151.5	162.8
Fpr.					
Compost C		< 0.001	< 0.001	< 0.001	< 0.001
Mineral fertilizer (M.F)		< 0.001	0.001	0.006	< 0.001
C x M.F		0.027	0.388	0.494	0.824

4.15.1.3 Nitrogen and phosphorus input and cowpea output in grain and haulm

Nitrogen input on cowpea was generally higher in 2014 than in 2013 (Table 4.28). Cowpea nitrogen output was significant (P < 0.001 and P = 0.026) under the sole application of compost in both cropping seasons while the interaction was significant (P = 0.042) only in 2013 cropping season. The higher values of 69.0 and 79.0 kg ha^{-1} of nitrogen input were obtained under combined application of 5000 kg ha^{-1} compost + 100 kg ha^{-1} DAP in 2013 and 2014, respectively. Higher cowpea nitrogen output values of 21.5 and 25.3 kg ha^{-1} resulted also from the combined application of 2500 kg ha^{-1} compost + 75 kg ha^{-1} DAP and 5000 kg ha^{-1} compost + 75 kg ha^{-1} DAP respectively in

2013 and in 2014 cropping seasons. On the other hand, phosphorus input was higher in 2014 than 2013 under the sole application of compost and its combination with DAP fertilizer (Table 4.28). The highest P input values of 170.6 and 181.6kg ha^{-1} was obtained under the combined application of 5000 kg ha^{-1} compost + 100 kg ha^{-1} DAP mineral fertilizer in both years. Phosphorus output was significant (P < 0.001 (2013) and P = 0.013 (2014)) only under the sole application of compost. The higher cowpea P output values of 4.1 kg ha^{-1} (2013) and 4.3 kg ha^{-1} (2014) were obtained by applying 2500 kg ha^{-1} + 75 kg ha^{-1} DAP and 5000 kg ha^{-1} + 75 kg ha^{-1} DAP mineral fertilizer.

Table 4.28: Cowpea nitrogen and phosphorus input and output (uptake) during the 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})		N input		N output		P input		P output	
		kg ha^{-1}				kg ha^{-1}			
Compost	DAP fertilizer	2013	2014	2013	2014	2013	2014	2013	2014
0	0	0.0	0.0	10.2	4.1	0.0	0.0	2.0	0.8
	50	9.0	9.0	12.1	7.0	10.0	10.0	2.1	1.3
	75	13.5	13.5	12.4	6.0	15.1	15.1	2.1	1.1
	100	18.0	18.0	16.2	9.7	20.1	20.1	2.6	1.5
2500	0	25.5	30.5	19.8	8.8	75.3	80.8	3.6	1.1
	50	34.5	39.5	18.0	16.1	85.3	90.8	3.3	3.0
	75	39.0	44.0	21.5	14.0	90.3	95.8	4.1	2.5
	100	43.5	48.5	17.0	9.5	95.3	100.8	3.2	2.1
5000	0	51.0	61.0	14.3	10.1	150.5	161.5	2.7	1.7
	50	60.0	70.0	19.3	14.3	160.5	171.5	3.6	3.0
	75	64.5	74.5	16.0	25.3	165.6	176.6	3.5	4.3
	100	69.0	79.0	13.7	12.2	170.6	181.6	2.8	2.1
Fpr.									
Compost				< 0.001	0.026			< 0.001	0.013
M. F				0.503	0.215			0.294	0.097
C x M.F				0.042	0.489			0.13	0.526

4.1.15.4 Cowpea nitrogen and phosphorus partial balance

Cowpea N and P partial balances were calculated under sole and integrated use of compost and DAP mineral fertilizer as presented in Table 4.29. Significant differences ($P < 0.001$) for N and P partial balances were found under the sole application of compost and DAP mineral fertilizer in both cropping seasons. Negative cowpea N partial balances were found under control (- 10.8 and – 4.1 kg ha^{-1}) in both 2013 and

2014 cropping seasons and also under the sole application 50 kg ha^{-1} DAP (-3.1 kg ha^{-1}). Higher values of cowpea positive N partial balance of 55.3 and 66.8 kg ha^{-1} were recorded under the application of 5000 kg ha^{-1} + 100 kg ha^{-1} DAP during both years.

On the other hand, cowpea P partial balances were positive under all treatments except the control (Table 4.29). Higher values of 167.8 and 179.5 kg ha^{-1} were recorded under the combined application of 5000 kg ha^{-1} compost + 100 kg ha^{-1} DAP mineral fertilizer respectively in 2013 and 2014 cropping seasons. The sole application of compost and mineral fertilizer significantly ($P < 0.001$) affected cowpea P partial balances in both years.

Table 4.29: Cowpea nitrogen and phosphorus partial balance during 2013 and 2014 cropping seasons

Treatments (kg ha^{-1})		N balance (kg ha^{-1})		P balance (kg ha^{-1})	
Compost	DAP fertilizer	2013	2014	2013	2014
0	0	-10.2	-4.1	-2.0	-0.8
	50	-3.1	2.0	7.9	8.8
	75	1.1	7.5	12.9	14.0
	100	1.8	8.3	17.5	18.5
2500	0	5.7	21.7	71.6	79.6
	50	16.5	23.4	82.0	87.8
	75	17.5	30.0	86.2	93.3
	100	26.5	39.0	92.1	98.7
5000	0	36.8	50.9	147.8	159.8
	50	40.7	55.7	156.9	168.6
	75	48.5	49.2	162.1	172.2
	100	55.3	66.8	167.8	179.5
Fpr.					
Compost (C)		< 0.001	< 0.001	< 0.001	< 0.001
Mineral Fertilizer (M.F)		< 0.001	0.002	< 0.001	< 0.001
C x M.F		0.042	0.489	0.133	0.53

4.15.2 Discussion

4.15.2.1 Evaluation of nitrogen and phosphorus partial balance of combined application of composted cattle manure and mineral fertilizer under strip cropping

The nitrogen input on pearl millet and cowpea was significant ($P < 0.001$ and $P = 0.026$) for cowpea under the sole application of compost in both years. These results are contrary to the findings of Opoku (2011) who showed that the resource base of the farming systems in Garin Labo (Niger) had no significant effect on their N inputs although equipped crop-livestock system supplied more N through manure than the other systems. The nitrogen and phosphorus inputs (Tables 4.26 and 4.28) observed in the study far outweighed the amount actually applied by farmers. De Rouw and Rajot (2004) reported extremely low levels of manure input 500 - 1,000 kg ha^{-1} per year, which added about 10 kg N, 1.2 kg P and 5 kg K to the soil in Niger. Nowadays this rate has increased due to the gains obtained by farmers and the fact that most farmers own cattle for agricultural traction. Kangalawe (2014) reported an average of 1,200 kg manure being produced by one livestock unit in a year. The positive N partial balance obtained under combined application of compost and NPK mineral fertilizer in 2013 may be due to the high nutrient content resulted from these treatments. Ngala *et al.* (2013) reported that increasing the level of NPK fertilizer and farmyard manure subsequently increased N-balances. In addition, Omae *et al.* (2014) reported the greatest and positive N balance under manure application, followed by millet husk in the intercropped millet - cowpea system in sahelian condition of Niger. Also under mixed farming systems in Ethiopia with cereals, oil crops, pulses, vegetables and permanent crops, the partial balances were positive for all nutrients considered (N, P and K) at the national scale (Haileslassie *et al.*, 2005).

Higher positive P partial balances were observed under integrated use of compost and mineral fertilizer for both pearl millet and cowpea in 2013 and 2014 (Tables 4.27 and 4.29). Kanté *et al.* (2007) found that positive partial P balance in Mali ranging from 2.9 to 6.6 kg ha^{-1} resulted from farmers�something farms under good, medium and unfavorable soil fertility management. The positive P partial balances could be explained by the high rate of P input (Tables 4.26 and 4. 28) and the low P uptake due to soil solution P – root P uptake mechanisms. Richardson *et al.* (2009) reported that uptake of P from the soil depends on both the rate of dissolution of orthophosphate (HPO_4^{2-} and $H_2PO_4^{-}$) towards roots and growth of the root system to intercept new sources of P. According to Malboobi *et al.* (2012), the low rate of P diffusion through soil (10^{-12} – 10^{-15} m/s) to roots effectively limits the uptake of P and restricts plant growth, unless roots can grow into and extract P from unexploited soil.

CHAPTER FIVE

5.0 Summary, conclusions and recommendations

5.1 Summary

i. Nitrogen, phosphorus, calcium and magnesium contents of manure increased as at the end of the composting process. Increases of 191.4 (2013) to 320.0 % (2014); 61.5 (2013) to 840.0 % (2014); 10.0 (2013) to 566.6 % (2014) and 11.1 (2013) to 600.0 % (2014) were recorded respectively for N, P, Ca and Mg. Decomposition of matured compost under field conditions showed that 40.3 % (2013) and 56.5 % (2014) of composted cattle manure decomposed after 84 days.

ii. Pearl millet grain yields of 1226.5 and 1233.0 kg ha^{-1} over the two cropping seasons were obtained under the application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 5000 kg ha^{-1} compost + 175 kg ha^{-1} NPK fertilizer respectively. Similarly, straw yields of 4666.5 and 3354.0 kg ha^{-1} over the two cropping seasons were recorded under the same treatments. Cowpea grain yields of 301.3 and 332.8 kg ha^{-1} over the two cropping seasons were obtained under the application of 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP and 5000 kg ha^{-1} compost + 50 kg ha^{-1}. The higher mean haulm yield values of 508.5 kg ha^{-1} (2500 kg ha^{-1} + 75 kg ha^{-1} DAP) and 496.0 kg ha^{-1} (5000 kg ha^{-1} compost + 75 kg ha^{-1} DAP) were obtained under integrated use of compost and mineral fertilizer over the two cropping seasons.

iii. Application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 5000 kg ha^{-1} compost +

175 kg ha^{-1} NPK was quite highly promising (sustainable) for pearl millet production with SYI of 0.64 and 0.65 respectively over the 2013 and 2014 cropping seasons. For cowpea production, application of 5000 kg ha^{-1} compost with 50 and 75 kg ha^{-1} DAP was highly promising with SYI of 0.63 and 0.57 respectively over the 2013 and 2014 cropping seasons. Pearl millet nitrogen and phosphorus use efficiencies means of 91.3 and 373.0 kg kg^{-1} over the two years (2013 and 2014) were obtained respectively under combined the application of 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK and 5000 kg ha^{-1} + 100 kg ha^{-1} NPK. The highest cowpea NUE of 33.7 kg ha^{-1} was obtained under 5000 kg ha^{-1} compost + 50 kg ha^{-1} DAP while the highest PUE of 197.9 kg kg^{-1} was recorded under the application of 5000 kg ha^{-1} + 100 kg ha^{-1} during the 2014 cropping season. Net return of US $366.3 led to 233.8 % RII with a VCR of 1.8 for pearl millet under the application of 2500 kg ha^{-1} + 175 kg ha^{-1} NPK. However, cowpea net return of US $37.5 led to 288.3 % RII and a VCR of 1.1 which was obtained by applying 2500 kg ha^{-1} compost + 50 kg ha^{-1} DAP.

iv. Higher positive partial nutrient balances were obtained under combined use of compost and mineral fertilizer for N and P during both years. Positive partial balances of 50.4 (2013) and 58.6 kg ha^{-1} (2014) for N and 151.5 (2013) and 162.8 kg ha^{-1} (2014) for P were obtained for pearl millet under the combined application of 5000 kg ha^{-1} + 200 kg ha^{-1} NPK. In the case of cowpea, higher positive partial balances of 55.3 (2013) and 66.8 kg ha^{-1} (2014) for N and 167.8 (2013) and 179.5 kg ha^{-1} (2014) for P resulted from the combined application of 5000 kg ha^{-1} + 100 kg ha^{-1} DAP.

5.2 Conclusions

Composting cattle manure with cowpea haulm (rich in N content) is a way of improving the fertilizer value of cattle manure. High decomposition and nutrient release of compost under field conditions were dependent on high and well distributed rainfall. The peak of compost nutrient release could be used to synchronize the peak nutrient demand of crops. The increase in soil nutrients following amendment application suggests that continuous application could result in a buildup of soil fertility.

Increased plant height, LAI, CGR and NAR resulted from the combined application of composted cattle manure and mineral fertilizer which consequently led to higher grain and straw/haulm yields relative to average yields under farmer"s field.

The high yield obtained following the combined application of compost and mineral fertilizer and its associated positive net benefit are good incentives for the acceptability of this management practice by farmers. High sustainability yield index was observed under the combined application of composted cattle manure and mineral fertilizer.

Positive partial N and P nutrient balances (the most limiting nutrients in Niger) could be obtained by using compost and mineral fertilizer under pearl millet and cowpea strip cropping system.

5.3 Recommendations

Even though this study has sufficiently addressed some of the relevant issues in the management of composted cattle manure and its combination with mineral fertilizer, the following recommendations can be examined for further research:

i. Due to optimum pearl millet and cowpea yields obtained under the combined 2500 kg ha^{-1} compost + 175 kg ha^{-1} NPK/50 DAP, in addition to high sustainablity yield index and positive net benefit, this treatment is recommended to farmers for sustainable crop production. ii. Studies exploring other available local organic materials in the study area (e.g. S*esbania pachycarp*a) for improving manure fertilizer value through composting should be carried out under farmer field managed conditions. Futhermore, a guide describing all the stages of composting should be developed for farmers.

iii. With the determination of peak nutrient release of the compost under field conditions, mechanisms underlying synchronization of nutrient release and crop uptake must be given the needed research attention.

REFERENCES

Abdel-Rahman, G. (2009). Impact of compost on soil properties and crop productivity in the sahel North Burkina Faso. *American Eurasian Journal of Agriculture and Environment Science* 6(2): 220-226.

Abdoulaye, T. and Sanders, J. H. (2005). Stages and determinants of fertilizer use in semiarid African agriculture: the Niger experience. *Agricultural Economics* 32(2): 167-179.

Abunyewa, A., Osei, C., Asiedu, E. and Safo, E.Y. (2007). Integrated manure and fertilizer use, maize production and sustainable soil fertility in sub humid zone of West Africa. *Journal of Agronomy 6(2) 302-309.*

Adamou, A., Bationo, A., Tabo, R. and Koala, S. (2007). Improving soil fertility through the use of organic and inorganic plant nutrient and crop rotation in Niger. pp. 589-598. In A. Bationo, B. Waswa, J. Kihira and J. Kimetu (eds.). Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. *Springer, Netherlands.*

Aihou, K., Sanginga, N., Vanlauwe, B., Lyasse, O., Diels, J. and Merckx, R. (1998). Alley cropping in the moist savanna of West-Africa: I. Restoration and maintenance of soil fertility on‟terre de barre „soils in Bénin Republic. *Agroforestry Systems* 42(3): 213-227.

Ajeigbe, H., Oseni, T., Singh, B. and Tarawali, S. (2007). Effect of different cowpeacereal row to row planting systems and insecticide sprays of cowpea on the quality of the crop residues. pp. 1057-1061. In *8th African Crop Science Society Conference, El-Minia, Egypt, 27-31 October 2007.* African Crop Science Society.

Akponikpe, P. B., Michels, K. and Bielders, C. L. (2008). Integrated nutrient management of pearl millet in the Sahel combining cattle manure, crop residue and mineral fertilizer. *Experimental Agriculture* 44(04): 453-472.

Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems and Environment* 74(1): 19-31.

Amanullah, M. J. H., Nawab, K. and Ali, A. (2007). Response of Specific Leaf Area (SLA), Leaf Area Index (LAI) and Leaf Area Ratio (LAR) of Maize (*Zea mays* L.) To Plant Density, Rate and Timing of Nitrogen Application. *World Applied Sciences Journal* 2 (3): 235-243.

Anderson, J. M. and Ingram, J. S. (1998). Tropical soil biology and fertility: a hand book of Methods of Analysis. *CAB International. pp. 39.*

Arthur, A. (2009). Effect of decomposing crop residues on soil properties and crop productivity in the semi - deciduous forest zone of Ghana. PhD Thesis, Faculty of Agriculture, Kwame Nkurmah University of Science and Technology. pp. 158.

Augustin, C. and Rahman, S. (2010). Composting Animal Manures: A guide to the process and management of animal manure compost. *Extension service North Dakota University*.

Ayeni, L. and Adeleye, E. (2012). Effect of cattle dung and urea fertilizer on pH and cations of soils selected from agro-ecological zones of Nigeria. *International Journal of Soil Science* 7(3): 82-90.

Azeez, J. and Van Averbeke, W. (2010). Nitrogen mineralization potential of three animal manures applied on a sandy clay loam soil. *Bioresoure Technology* 101(14): 5645-5651.

Badiane, A., Faye, A., Yamoah, C. F. and Dick, R. (2001). Use of compost and mineral fertilizers for millet production by farmers in the semiarid region of Senegal. *Biological Agriculture and Horticulture* 19(3): 219-230.

Baidu-Forson, J. and Bationo, A. (1992). An economic evaluation of a long-term experiment on phosphorus and manure amendments to sandy Sahelian soils: Using a stochastic dominance model. *Fertilizer Research* 33(3): 193-202.

Baldock, J. O. and Musgrave, R. B. (1980). Manure and mineral fertilizer effects in continuous and rotational crop sequences in central New York. *Agronomy Journal* 72(3): 511-518.

Bationo, A., Hartemink, A., Lungu, O., Naimi, M., Okoth, P., Smaling, E. and Thiombiano, L. (2006a). African soils: their productivity and profitability of fertilizer use. Background paper prepared for the African Fertilizer Summit June 9–13, 2006, Abuja, Nigeria, 25p. [Kampala]: *Tropical Soil Biology and Fertility Institute of CIAT* [etc.].

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B. and Kimetu, J. (2006b). Soil organic carbon dynamics, functions and management in West African agroecosystems. *Agricultural Systems* 94(1): 13-25.

Bationo, A. and Mokwunye, A. (1991). Role of manures and crop residue in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Sudanian zones of West Africa. Fertilizer Research 29, 117–125.

Bationo, A., Nandwa, S. M., Kimetu, J. M., Kinyangi, J. M., Bado, B. V., Lompo, F., Kimani, S., Kihanda, F. and Koala, S. (2004). Sustainable intensification of crop-livestock systems through manure management in eastern and western Africa: lessons learned and emerging research opportunities. pp. 173–198. In Williams, T.O., Tarawali, S., Hiernaux, P., Fernandez- Rivera, S. (Eds.). Proceedings of the International Conference on Sustainable Crop-livestock Production for Improved Livelihoods and Natural Resource Management in West Africa. International Livestock Research Institute, Addis Abeba, Ethiopia.

Bationo, A., Traore, Z., Kimetu, J., Bagayoko, M., Kihara, J., Bado, V., Lompo, M., Tabo, R. and Koala, S. (2003). Cropping systems in the Sudano-sahelian zone: Implications on soil fertility management. pp. 137-158. In Bationo, A., Waswa, B., Kihara, J., Adolwa, I., Vanlauwe, B., & Saidou, K. (Eds.). Lessons learned from Long-term soil fertility management experiments in Africa. *Springer Netherlands*.

Bouajila, K. and Sanaa, M. (2011). Effects of organic amendments on soil physicochemical and biological properties. *Journal of Materials and Environmental Science* 2: 485-490.

Branca, G., Tennigkeit, T., Mann, W. and Lipper, L. (2011). Identifying opportunities for climate-smart agriculture investments in Africa. Rome: Food and Agriculture Organization of the United Nation & World Bank.

Bray, R. H. and Kurtz, L. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science* 59(1): 39-46.

Bremner, J. and Edwards, A. (1965). Determination and isotope-ratio analysis of different forms of nitrogen in soils: I. Apparatus and procedure for distillation and determination of ammonium. *Soil Science Society of America Journal* 29(5): 504-507.

Brown, S. and Cotton, M. (2011). Changes in soil properties and carbon content following compost application: results of on-farm sampling. *Compost Science and Utilization* 19(2): 87-96.

Buchholz, D. D., Brown, J. R., Garret, J., Hanson, R. and Wheaton, H. (2004). Soil test interpretations and recommendations handbook. University of MissouriCollege of Agriculture, Division of Plant Sciences.

Buerkert, A., Bationo, A. and Piepho, H.-P. (2001a). Efficient phosphorus application strategies for increased crop production in sub-Saharan West Africa. *Field Crops Research* 72(1): 1-15.

Buerkert, A., Moser, M., Kumar, A. K., FuÈrst, P. and Becker, K. (2001b). Variation in grain quality of pearl millet from Sahelian West Africa. *Field Crops Research* 69(1): 1-11.

Buresh, R. and Giller, K. (1998). Strategies to replenish soil fertility in African smallholder agriculture. Soil Fertility Research for Maize-Based Farming Systems in Malawi and Zimbabwe; Mutare,(Zimbabwe); 7-11 Jul 1997. Proceedings of the Soil Fertility Network Results and Planning Workshop.

Chen, J.-H., Wu, J.-T. and Huang, W.-T. (2001). Effects of compost on the availability of nitrogen and phosphorus in strongly acidic soils. Food and Fertilize Technology Center for the Asian and Pacific Region (FAO).

Chivenge, P., Vanlauwe, B., Gentile, R., Wangechi, H., Mugendi, D., van Kessel, C. and Six, J. (2009). Organic and Mineral Input Management to Enhance Crop Productivity in Central Kenya. *Agronomy Journal* 101(5): 1266.

Chukwuka, K. (2009). Soil fertility restoration techniques in sub-Saharan Africa using organic resources. *African Journal of Agricultural Research* 4(3): 144-150.

De Jager, A., Nandwa, S. M. and Okoth, P. F. (1998). Monitoring nutrient flows and economic performance in African farming systems (NUTMON): I. Concepts and methodologies. *Agriculture, Ecosystems and Environment* 71(1): 37-48.

De Rouw, A. and Rajot, J.-L. (2004). Nutrient availability and pearl millet production in Sahelian farming systems based on manuring or fallowing. *Agriculture, Ecosystems and Environment* 104(2): 249-262.

Dhanya, B., Viswanath, S. and Purushothaman, S. (2013). Decomposition and Nutrient Release Dynamics of *Ficus benghalensis* L. Litter in Traditional Agroforestry Systems of Karnataka, Southern India. *International Scholarly Research Notices* 2013.

Diangar, S., Fofana, A., Diagne, M., Yamoah, C. and Dick, R. (2004). Pearl milletbased intercropping systems in the semiarid areas of Senegal. *African Crop Science Journal* 12(2): 133-139.

Dugje, I., Omoigui, L., Ekeleme, F., Kamara, A. and Ajeigbe, H. (2009). Production du niébé en Afrique de l‟Ouest: Guide du paysan. *Document de l'IITA* 20.

Efthimiadou, A., Bilalis, D., Karkanis, A. and Froud-Williams, B. (2010). Combined organic/inorganic fertilization enhance soil quality and increased yield, photosynthesis and sustainability of sweet maize crop. *Australian Journal of Crop Science* 4(9): 722-729.

Eghball, B., Power, J. F., Gilley, J. E. and Doran, J. W. (1997). Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure. *Journal of Environmental Quality* 26(1): 189-193.

Eghball, B., Wienhold, B. J., Gilley, J. E. and Eigenberg, R. A. (2002). Mineralization of manure nutrients. *Journal of Soil and Water Conservation* 57(6): 470-473.

El-Lattief, A. E. (2011). Growth and fodder yield of forage pearl millet in newly cultivated land as affected by date of planting and integrated use of mineral and organic fertilizers. *Asian Journal of Crop Science* 3: 35-42.

Esse, P. C., Buerkert, A., Hiernaux, P. and Assa, A. (2001). Decomposition of and nutrient release from ruminant manure on acid sandy soils in the Sahelian zone of Niger, West Africa. *Agriculture, Ecosystems and Environment* 83: 55-63.

Ewusi–Mensah, N. (2009). Optimizing manure quality for increased food production on small holder farms in the upper east region of Ghana. PhD Thesis, Faculty of Agriculture, Kwame Nkurma University of Science and Technology, Kumasi, Ghana.

Fairhurst, T. (2012). Handbook for integrated soil fertility management. *Africa Soil Health Consortium: Wallingford, UK.*

FAO (2000). Fertilizers and their use fourth edition. *FAO, Rome 1965*.

FAO (2003). Scaling nutirent balances. *FAO Rome*.

FAO (2006). Guidelines for soil description, Fourth edition. *Rome*.

Fatondji, D. (2002). Organic amendment decomposition, nutrient release and nutrient uptake by millet (*Pennisetum glaucum* (L.) R. Br.) in a traditional land rehabilitation technique (Zaï) in the Sahel. PhD Thesis, University of Bonn, Germany.

Fatondji, D., Martius, C., Bielders, C. L., Vlek, P. L. G., Bationo, A. and Gerard, B. (2006). Effect of planting technique and amendment type on pearl millet yield, nutrient uptake, and water use on degraded land in Niger. *Nutrient Cycling in Agroecosystems* 76(2-3): 203-217.

Fatondji, D., Martius, C., Bielders, C. L., Vlek, P. L. G., Bationo, A. and Gerard, B. (2009). Decomposition of organic amendment and nutrient release under the zai technique in the Sahel. *Nutrient Cycling in Agroecosystems* 85: 225–239.

Fening, J. O., Ewusi-Mensah, N. and Safo, E. Y. (2010). Improving the fertilizer value of cattle manure for sustaining small holder crop production in Ghana. *Journal of Agronomy* 9(3): 92-101.

Fofana, B., Wopereis, M., Bationo, A., Breman, H. and Mando, A. (2008). Millet nutrient use efficiency as affected by natural soil fertility, mineral fertilizer use and rainfall in the West African Sahel. *Nutrient Cycling in Agroecosystems* 81(1): 25-36.

Francis, C. (1986). Distribution and importance of multiple cropping. *Multiple Cropping. New York: McMillan*: 15-19.

Franzluebbers, A., Haney, R., Hons, F. and Zuberer, D. (1996). Active fractions of organic matter in soils with different texture. *Soil Biology and Biochemistry* 28(10): 1367-1372.

Freymann, B. P., Buitenwerf, R., Desouza, O. and Olff, H. (2008). The importance of termites (Isoptera) for the recycling of herbivore dung in tropical ecosystems: a review. *European Journal of Entomology* 105(2): 165.

Garba, M. and Renard, C. (1991). Biomass production, yields and water use efficiency in some pearl millet/legume cropping systems at Sadore, Niger. *International Association of Hydrological Sciences, Wallingford, (Englend). 1991.*

Ghosh, P. K., Ramesh, P., Bandyopadhyay, K. K., Tripathi, A. K., Hati, K. M., Misra, A. K. and Acharya, C. L. (2004). Comparative effectiveness of cattle manure, poultry manure, phosphocompost and fertilizer-NPK on three cropping systems in vertisols of semi-arid tropics. I. Crop yields and system performance. *Bioresource Technology* 95(1): 77-83.

Gnankambary, Z., Bayala, J., Malmer, A., Nyberg, G. and Hien, V. (2008). Decomposition and nutrient release from mixed plant litters of contrasting quality in an agroforestry parkland in the south-Sudanese zone of West Africa. *Nutrient Cycling in Agroecosystems* 82(1): 1-13.

Habib, M. D., Asif, M., Aziz, M., Ali, A., Ashraf, M., Mahmood, A. and Javaid, M. M. (2012). Growth performance of spring maize and soil fertility status as influenced by nutrient sources. *Intertional Journal of Agricultural and Applied Science Vol* 4(1).

Hagedorn, F., Steiner, K., Sekayange, L. and Zech, W. (1997). Effect of rainfall pattern on nitrogen mineralization and leaching in a green manure experiment in South Rwanda. *Plant and Soil* 195(2): 365-375.

Haglund, E., Ndjeunga, J., Snook, L. and Pasternak, D. (2011). Dry land tree management for improved household livelihoods: farmer managed natural regeneration in Niger. *Journal of Environmental Management* 92(7): 1696-1705.

Haile, W., Boke, S. Abd Box, P. (2009). Mitigation of soil acidity and fertility decline challenges for sustainable livelihood improvement: research findings from souther region of ethiopia and its policy implications. Awassa Agricultural Research Institute.

Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D. and Lesschen, J. P. (2005). Assessment of soil nutrient depletion and its spatial variability on smallholders" mixed farming systems in Ethiopia using partial versus full nutrient balances. *Agriculture, Ecosystems and Environment* 108(1): 1-16.

Hanson, R. (1992). Optimum phosphate fertilizer products and practices for tropicalclimate agriculture. *Food and Agricultural Organisation* (*FAO) and International Information System for the Agricultural Science and Technology (AGRIS).*

Harris, F. (2002). Management of manure in farming systems in semi-arid west africa. *Experimental Agriculture* 38: 131-148.

Harris, F. and Yusuf, M. (2001). Manure management by smallholder farmers in the Kano Close-Settled Zone, Nigeria. *Experimental Agriculture* 37(03): 319-332.

Haseeb-ur, R., Ali, A., Muhammad, W., Tanveer, A., Tahir, M., Nadeem, M. and Zamir, M. (2010). Impact of Nitrogen Application on Growth and Yield of Maize (Zea mays L.) Grown Alone and in Combination with Cowpea (Vigna unguiculata L.). *American-Eurasian Journal of Agricultural and Environmental Sciences* 7(1): 43-47.

Hatfield, J. L., Sauer, T. J. and Prueger, J. H. (2001). Managing soils to achieve greater water use efficiency. *Agronomy Journal* 93(2): 271-280.

Hati, K. M., Swarup, A., Dwivedi, A., Misra, A. and Bandyopadhyay, K. (2007). Changes in soil physical properties and organic carbon status at the topsoil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring. *Agriculture, Ecosystems and Environment* 119(1): 127-134.

Hossner, L. R. and Juo, A. S. (1999). Soil nutrient management for sustained food crop production in upland farming systems in the tropics. Food and Fertilizer Technology Center. http://www.agnet.org/htmlarea_file/library.

Hussein, M., Kassab, O. and Aboellil, A. (2011). Effect of Combined Fertilizer and Drought on Growth and Yield of Millet. *Journal of Applied Sciences Research* 7(12): 2462-2469.

Issaka, M. (2001). Évolutions à long terme de la fertilité de sol dans la région de Maradi. Working Paper No. 30, Drylands Research, Crewkerne, United Kingdom.

Jost, D. I., Joergensen, R. G. and Sundrum, A. (2013). Effect of cattle faeces with different microbial biomass content on soil properties, gaseous emissions and plant growth. *Biology and Fertility of Soils* 49(1): 61-70.

Kangalawe, R. Y. (2014). Nutrient budget analysis under smallholder farming systems and implications on agricultural sustainability in degraded environments of semiarid central Tanzania. *Journal of Soil Science and Environmental Management* 6: 44-60.

Kanté, S., Smaling, E. M. A. and Van Keulen, H. (2007). Nutrient balances for different farm types in Southern Mali. pp. 557-566. In A. Bationo, B. Waswa, J. Kihira and J. Kimetu (eds.). Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. *Springer, Netherlands*.

Kapkiyai, J., Karanja, N., Woomer, P. and Qureshi, J. (1998). Soil organic carbon fractions in a long-term experiment and the potential for their use as a diagnostic assay in highland farming systems of Central Denya. *African Crop Science Journal*, **6**: 19-28.

Khaliq, A., Abbasi, M. K. and Hussain, T. (2006). Effects of integrated use of organic and inorganic nutrient sources with effective microorganisms (EM) on seed cotton yield in Pakistan. *Bioresource Technology* 97(8): 967-972.

Khan, A., Jan, M. T., Marwat, K. B. and Arif, M. (2009). Organic and inorganic nitrogen treatments effects on plant and yield attributes of maize in a different tillage systems. *Pakistan Journal of Botanic* 41(1): 99-108.

Kiani, M. J., Abbasi, M. K. and Rahim, N. (2005). Use of organic manure with mineral N fertilizer increases wheat yield at Rawalakot Azad Jammu and Kashmir. *Archives of Agronomy and Soil Science* 51(3): 299-309.

Kihanda, F., Warren, G. and Micheni, A. (2007). Effects of manure application on crop yield and soil chemical properties in a long-term field trial in semi-arid Kenya. pp.471-486. In A. Bationo, B. Waswa, J. Kihira and J. Kimetu (eds.). Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. *Springer, Netherlands.*

Kihara, J., Kimetu, J., Vanlauwe, B., Bationo, A., Waswa, B. and Mukalama, J. (2007). Optimising crop productivity in legume-cereal rotations through nitrogen and phosphorus management in western Kenya. pp.493-502. In A. Bationo, B. Waswa, J. Kihira and J. Kimetu (eds.). Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. *Springer, Netherlands*.

Kramer, A. W., Doane, T. A., Horwath, W. R. and Kessel, C. V. (2002). Combining fertilizer and organic inputs to synchronize N supply in alternative cropping systems in California. *Agriculture, Ecosystems and Environment* 91(1): 233-243.

Ladha, J. K., Pathak, H., Krupnik, T. J., Six, J. and van Kessel, C. (2005). Efficiency of fertilizer nitrogen in cereal production: retrospects and prospects. *Advances in Agronomy* 87: 85-156.

Landon, J. R. (2014). Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman. 431pp.

Lehmann, J. and Schroth, G. (2003). Nutrient leaching. pp. 151-166. In Schroth, G., and Sinclair, F. (eds.). Trees, Crops and Soil Fertility, CABI Publishing, Wallingford.

Lithourgidis, A., Dordas, C., Damalas, C. and Vlachostergios, D. (2011). Annual intercrops: an alternative pathway for sustainable agriculture. *Australian Journal of Crop Science* 5(4): 396.

Mahaman, I. (1988). Row broadcast, hill, or strip placement of P fertilizer on millet and rice in Niger. Unpublished Master's Thesis, Agronomy Department, Purdue University, W. Lafayette, IN.

Malboobi, M. A., Samaeian, A., Sabet, M. S. and Lohrasebi, T. (2012). Plant Phosphate Nutrition and Environmental Challenges. INTECH Open Access Publisher.

Manu, A., Bationo, A. and Geiger, S. C. (1991). Fertility status of selected millet producing soils of west africa with emphasis on phosphorus. *Soil Science* 152(5): 315-320.

Manyame, C. (2006). On-farm yield and water use response of pearl millet to different management practices in Niger, PhD. Thesis. Texas A and M University.

Marshall, T. and Holmes, J. (1988). Soil physics Second edition. Cambridge University press. pp. 57 - 58.

Mason, S. C., Maman, N. and Palé, S. (2014). Pearl millet production practices in semi-arid West Africa: Review. *Experimental Agriculture - Cambridge University Press*: 1-21.

McLean, E. O. (1965). Aluminium. C.A. Black (ed.) Methods of soil analysis, Part 2. *Agronomy* 9: 976-994.

Mehmood, Y., Anjum, M., Sabir, M. and Arshad, M. (2011). Benefit cost ratio of organic and inorganic wheat production: a case study of district Sheikhupura. *World Applied Sciences Journal* 13: 175-180.

Metson, A. (1961). Methods of chemical analysis for soil survey samples. Department of Scientific and Industrial Research. New Zealand. Soil Bureau bulletin 12.

Moore, J., Klose, S. And Tabatabai, M. (2000). Soil microbial biomass carbon and nitrogen as affected by cropping systems. *Biology and Fertility of Soils* 31(3-4): 200-210.

Mosier, A. R., Syers, J. K. and Freney, J. R. (2004). Agriculture and the Nitrogen Cycle. Assessing the Impacts of Fertilizer Use on Food Production and the Environment. . *Scope-65 Island Press, London.*

Mtambanengwe, F., Mapfumo, P. and Vanlauwe, B. (2007). Comparative short-term effects of different quality organic resources on maize productivity under two different environments in Zimbabwe. pp. 575-588. In A. Bationo, B. Waswa, J. Kihira and J. Kimetu (eds.). Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. *Springer, Netherlands.*

Mucheru-Muna, M., Mugendi, D., Mugwe, J. and Kung'u, J. (2007). Economic evaluation of local inputs in Meru South District, Kenya. pp. 443-448. In A. Bationo, B. Waswa, J. Kihira and J. Kimetu (eds.). Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. *Springer, Netherlands.*

Nandwa, S. M. (2001). Soil organic carbon (SOC) management for sustainable productivity of cropping and agro-forestry systems in Eastern and Southern Africa. . *Nutrient Cycling in Agroecosystems* 61: 143-158.

Ncube, B., Dimes, J. P., Twomlow, S. J., Mupangwa, W. and Giller, K. E. (2006). Raising the productivity of smallholder farms under semi-arid conditions by use of small doses of manure and nitrogen: a case of participatory research. *Nutrient Cycling in Agroecosystems* 77(1): 53-67.

Nelson, D. and Sommers, L. E. (1982). Total carbon, organic carbon, and organic matter. *Methods of soil analysis. Part 2. Chemical and microbiological properties* (methodsofsoilan2): 539-579.

Ngakou, A., Megueni, C., Noubissie, E. and Tchuenteu, T. L. (2008). Evaluation of the physico-chemical properties of cattle and kitchen manures derived composts and their effects on field grown Phaseolus vulgaris L. *International Journal of Sustainaible Crop Production* 3(5): 13-22.

Ngala, A., Yakubu, H. and Tekwa, I. (2013). Partial balance of N, P and K in a sole millet crop on a sandy loam soil of Northeast Nigeria. *Journal of Soil Science and Environmental Mangement* 4(2): 17-22.

Nhamo, N. (2001). An evaluation of the efficacy of organic and inorganic fertilizer combinations in supplying nitrogen to crops. Unpublished M. Phil. Thesis, University of Zimbabwe, Harare, Zimbabwe.

Nwaiwu, I., Ohajianya, D., Lemchi, J., Ibekwe, U., Nwosu, F., Ben-chendo, N., Henri-Ukoha, A. and Kadiri, F. (2010). Economics Of Organic Manure Use By Food Crop Farmers In Ecologically Vulnerable Areas Of Imo State,Nigeria. *Researcher* 2(11).

Nziguheba, G., Palm, C. A., Buresh, R. J. and Smithson, P. C. (1998). Soil phosphorus fractions and adsorption as affected by organic and inorganic sources. *Plant and Soil* 198(2): 159-168.

Odhiambo, J. J. and Mag, V. N. (2008). An assessment of the use of mineral and organic fertilizers by smallholder farmers in Vhembe district, Limpopo province, South Africa. *African Journal of Agricultural Research* 3(5): 357-362.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (1993). Laboratory methods of soil and plant analysis: A working manual. Tropical Soil Bioliogy and Fertility. *Soil Science Society of East Africa. Technical Publication No. 1. Nairobi, Kenya.*: 88pp.

Olson, J. S. (1963). Energy storage and the balance of producers and decomposers in ecological systems. *Ecology* 44(2): 322-331.

Omae, H., Saidou, A. K. and Tobita, S. (2014). On farm evaluation of effect of organic and mineral fertilizer on biomass and yield of millet/cowpea intercrop in the sahel, West Africa. *Journal of life Sciences, ISSN 1934-7391, USA* 8(7): 582-592.

Ondieki, M., Aguyoh, J. and Opiyo, A. (2011). Fortified compost manure improves yield and growth of African nightshades. *Indien Journal of Engineering and Materials Sciences* 2(2): 231-237.

Onduru, D., Snijders, P., Muchena, F., Wouters, B., De Jager, A., Gachimbi, L. and Gachini, G. (2008). Manure and Soil Fertility Management in Sub-Humid and Semi-Arid Farming Systems of Sub-Saharan Africa: Experiences from Kenya. *International Journal of Agricultural Research* 3(3).

Opoku, A. (2011). Sustainability of Crop Residues and Manure Management in Smallholder Cereal-Legume-Livestock Systems in the Savannas of West Africa. PhD Thesis, Faculty of Agriculture, Kwame Nkurmah University of Science and Technology, Kumasi, Ghana.

Oseni, T. O. (2010). Evaluation of sorghum-cowpea intercrop productivity in savanna agro-ecology using competition indices. *Journal of Agricultural Science* 2(3): P229.

Oyetunji, O., Ekanakaye, I. and Osonubi, O. (2001). Influence of yam fungi on cassava-maize intercrop in an alley cropping system. In *Proceedings of African Crop Science Conference, Uganda,* Vol. 5, 1079-1083.

Partey, S., Quashie-Sam, S., Thevathasan, N. and Gordon, A. (2011). Decomposition and nutrient release patterns of the leaf biomass of the wild sunflower (Tithonia diversifolia): a comparative study with four leguminous agroforestry species. *Agroforestry Systems* 81(2): 123-134.

Paul, S., Onduru, D., Wouters, B., Gachimbi, L., Zake, J. and Ebanyat, P. (2009). Cattle manure management in East Africa. *assessment* 94: 289-298.

Pender, J., Abdoulaye, T., Ndjeunga, J., Gerard, B. and Kato, E. (2008). Impacts of inventory credit, input supply shops, and fertilizer microdosing in the drylands of Niger. International Food Policy Research Institute.

Peter, G. and Runge-Metzger, A. (1994). Monocropping, intercropping or crop rotation? An economic case study from the West African Guinea savannah with special reference to risk. *Agricultural systems* 45(2): 123-143.

Polania, J., Poschenrieder, C., Rao, I. and Beebe, S. (2015). Physiological basis of improved adaptation to drought in common bean. *Plant Physiology* 40: 503-537.

Premsekhar, M. and Rajashree, V. (2009). Influence of organic manures on growth, yield and quality of okra. *American Eurasian Journal of Sustainable Agriculture* 3(1): 6-8.

Quiñones, M. A., Borlaug, N. E. and Dowswell, C. R. (1997). A fertilizer-based green revolution for Africa. *Replenishing soil fertility in Africa* (replenishingsoi): 81-95.

Rezaei, E. E., Gaiser, T., Siebert, S., Sultan, B. and Ewert, F. (2014). Combined impacts of climate and nutrient fertilization on yields of pearl millet in Niger. *European Journal of Agronomy* 55: 77-88.

Richardson, A. E., Hocking, P. J., Simpson, R. J. and George, T. S. (2009). Plant mechanisms to optimise access to soil phosphorus. *Crop and Pasture Science* 60(2): 124-143.

Rinaudo, T. and Yaou, S. (2009). Agricultural Task Force Report: World Vision Niger Agricultural Development. *World Vision*: 4.

Roberts, T. L. (2008). Improving nutrient use efficiency. *Turkish Journal of Agriculture and Forestry* 32(3): 177-182.

Robertson, G. P., Solins, P., Ellis, B. G. and Lajitha, K. (1999). Exchangeable ions, pH, and cation exchange capacity. *Ecological Research. Oxford University Press, New York*: pp 106-114.

Ros, M., Klammer, S., Knapp, B., Aichberger, K. and Insam, H. (2006). Long‐term effects of compost amendment of soil on functional and structural diversity and microbial activity. *Soil Use and Management* 22(2): 209-218.

Roy, R. N., Misra, R. V., Lesschen, J. P. and Smaling, E. M. (2003). Assessment of soil nutrient balance. *FAO Fertilizer and Plant Nutrition Bulletin 14*.

Saidou, A. K., Omae, H. and Tobita, S. (2010a). Combination effect of crop design and crop densities in the system of millet/cowpea rotation in the sahel, West Africa. *American-Eurasian Journal of Agricultural and Environmental Sciences* 7(6): 644647.

Saidou, A. K., Omae, H. and Tobita, S. (2010b). Combination effect of intercropping, application of chemical fertilizer and transported manure on millet/cowpea growth and nitrogen, phosphorus balances in the Sahel. *American Eurasian Journal of Agronomy* 3(2): 30-35.

Sanchez, P. A. (2002). Soil fertility and hunger in Africa. *Science (Washington)* 295(5562): 2019-2020.

Sanchez, P. A., Shepherd, K. D., Soule, M. J., Place, F. M., Buresh, R. J., Izac, A.M. N., Mokwunye, A. U., Kwesiga, F. R., Ndiritu, C. G. and Woomer, P. L. (1997). Soil fertility replenishment in Africa: An investment in natural resource capital. *Replenishing soil fertility in Africa* (replenishingsoi): 1-46.

Sandeen, A. T. and Gamroth, M. J. (2003). Composting: an alternative for livestock manure management and disposal of dead animals. *Corvallis, Oregon Extension Service, Oregon State University*.

Sanginga, N. and Woomer, P.L. 2009. Integrated Soil Fertility Management in Africa: Principles, Practices and Developmental Process. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture. Nairobi. 263 pp.

Sarr, P. S., Khouma, M., Sene, M., Guisse, A., Badiane, A. N. and Yamakawa, T. (2008). Effect of pearl millet–cowpea cropping systems on nitrogen recovery, nitrogen use efficiency and biological fixation using the 15N tracer technique. *Soil Science and Plant Nutrition* 54(1): 142-147.

Sarwar, G., Schmeisky, H., Hussain, N., Muhammad, S., Ibrahim, M. and Safdar, E. (2008). Improvement of soil physical and chemical properties with compost application in rice-wheat cropping system. *Pakistan Journal of Botany* 40(1): 275282.

Schlecht, E., Buerkert, A., Tielkes, E. and Bationo, A. (2006). A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems* 76(2-3): 109-136.

Sebillotte, M. (1974). Agronomie et agriculture. Essai d‟analyse des tâches de l‟agronome. *Cahiers de l'ORSTOM* 24: 3-25.

Sinclair, T. R. and Weiss, A. (2010). Principles of ecology in plant production. *CABI*.

Singh, S. B. and Chauhan, S. K. (2014). Productivity and economics of pearl millet as influenced by integrated nutrient management. *Annals of Plant and Soil Research* 16(4): 356-358.

Smaling, E. M. A. (1993). An agro-ecological framework for integrated nutrient management with special reference to Kenya. Doctoral dissertation, *Landbouwuniversiteit te Wageningen*.

Smith, D. L. and Hamel, C. (2012). Crop yield: physiology and processes. Springer verlag berlin Heidelberg. pp. 271-286.

Snyder, C. and Bruulsema, T. (2007). Nutrient use efficiency and effectiveness in North America: indices of agronomic and environmental benefit. *International Plant Nutrition Institute. Reference* 7076.

Soil Laboratory Staff (1984). Analytical methods of the service Laboratory for soil, plant and water analysis. Part I: Methods for soil analysis. Royal Tropical Institute, Amsterdam.

Soon, Y. K., Clayton, G. W. and Rice, W. A. (2001). Tillage and previous crop effects on dynamics of nitrogen in a wheat–soil system. *Agronomy Journal* 93(4): 842-849.

Stoffella, P. J., Li, Y., Roe, N. E., Ozores-Hampton, M. and Graetz, D. A. (1997). Utilization of composted organic wastes in vegetable production systems. Asian and Pacific Concil (*ASPAC) Food and Fertilizer Technology Center.*

Tabo, R., Bationo, A., Gerard, B., Ndjeunga, J., Marchal, D., Amadou, B., Annou, M. G., Sogodogo, D., Taonda, J.-B. S. and Hassane, O. (2007). Improving cereal productivity and farmers‟ income using a strategic application of fertilizers in West Africa. pp. 201-208. In A. Bationo, B. Waswa, J. Kihira and J. Kimetu (eds.). Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. *Springer, Netherlands.*

Tetteh, F. K. M. (2004). Synchronizing nutrient release from decomposing organic materials with crop nutrient demand in the semi-deciduous forest zone of Ghana. PhD Thesis, Faculty of Agriculture, Kwame Nkurmah University of Science and Technology, Kumasi, Ghana.

Tkachuk, V. L., Krause, D. O., McAllister, T. A., Buckley, K. E., Reuter, T., Hendrick, S. and Ominski, K. H. (2013). Assessing the inactivation of Mycobacterium avium subsp. paratuberculosis during composting of livestock carcasses. *Applied and Environmental Microbiology* 79(10): 3215-3224.

Valero, J. D. J., Maturano, M., Ramírez, A. A., Martín-Benito, J. T. and Álvarez, J. O. (2005). Growth and nitrogen use efficiency of irrigated maize in a semiarid region as affected by nitrogen fertilization. *Spanish Journal of Agricultural Research* 3(1): 134-144.

Vandermeer, J. H. (1992). The ecology of intercropping. *Cambridge University Press*.

Vanlauwe, B., Aihou, K., Aman, S., Iwuafor, E. N., Tossah, B., Diels, J., Sanginga, N., Lyasse, O., Merckx, R. and Deckers, J. (2001). Maize yield as affected by organic inputs and urea in the West African moist savanna. *Agronomy Journal* 93(6): 1191-1199.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R. and Shepherd, K. (2010). Integrated soil fertility management operational definition and consequences for implementation and dissemination. *Outlook on Agriculture* 39(1): 17-24.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R. &Six, J. (2011). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant Soil* (339): 35–50.

Vanlauwe, B., Palm, C., Murwira, H. and Merckx, R. (2002). Organic resource management in sub-Saharan Africa: validation of a residue quality-driven decision support system. *Agronomie* 22(7-8): 839-846.

Vittal, K., Sankar, G. M., Singh, H. and Samra, J. (2002). Sustainability of practices of dryland agriculture: Methodology and assessment. *All India Coordinated Research Project for Dryland Agriculture, Central Research Institute for Dryland Agriculture, Indian Council of Agricultural Research, Hyderabad-500* 59(100): 3-4.

Watts, D., Torbert, H. and Prior, S. (2007). Mineralization of nitrogen in soils amended with dairy manure as affected by wetting/drying cycles. *Communications in soil science and plant analysis* 38(15-16): 2103-2116.

Weber, J., Karczewska, A., Drozd, J., Licznar, M., Licznar, S., Jamroz, E. and Kocowicz, A. (2007). Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts. *Soil Biology and Biochemistry* 39(6): 1294-1302.

Whalen, J. K., Chang, C., Clayton, G. W. and Carefoot, J. P. (2000). Cattle manure amendments can increase the pH of acid soils. *Soil Science Society of America Journal* 64(3): 962-966.

Wu, W. and Ma, B. (2015). Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: a review. *Science of The Total Environment* 512: 415-427.

Yamoah, C., Bationo, A., Shapiro, B. and Koala, S. (2003). Soil management practices to improve nutrient-use efficiencies and reduce risk in millet-based cropping systems in the Sahel. *Tropicultura* 21(2): 66-72.

Yamoah, C. F., Bationo, A., Shapiro, B. and Koala, S. (2002). Trend and stability analyses of millet yields treated with fertilizer and crop residues in the Sahel. *Field Crops Research* 75(1): 53-62.

Yu, W., Ding, X., Xue, S., Li, S., Liao, X. and Wang, R. (2013). Effects of organicmatter application on phosphorus adsorption of three soil parent materials. *Journal of soil science and plant nutrition* 13(4): 1003-1017.

Zhen, L. and Routray, J. K. (2003). Operational indicators for measuring agricultural sustainability in developing countries. *Environmental Management* 32(1): 34-46.

APPENDICES

Appendix 1: Summary of analysis of variance of soil physic-chemical parameters

Sources of variations	P values												
					Cmol$_+$ kg^{-1}								
	pH	Oc (%)	N (%)	P (mg/kg)	Ca	Mg	K	Na	Al	H	Bulk density	Moisture content	Volumetric water content (m^3 m^{-3})
C	0.344	0.122	0.506	0.234	0.121	0.193	0.111	0.498	0.679	0.348	< 0.001	0.941	0.853
M. F	0.009	0.816	0.204	0.223	0.95	0.409	0.964	0.999	0.406	0.146	0.915	0.44	0.458
Year	< 0.001	< 0.001	0.011	< 0.001	< 0.001	< 0.001	0.003	< 0.001	0.002	0.014	< 0.001	< 0.001	< 0.001
C x M.F	0.013	0.393	0.542	0.549	0.101	0.962	0.92	0.936	0.255	0.463	0.78	0.766	0.803
C x Y	0.933	0.123	0.795	0.099	0.013	0.608	0.085	0.562	0.402	0.537	0.067	0.935	0.984
M.F x Y	0.387	0.707	0.083	0.301	0.742	0.729	0.819	0.988	0.283	0.724	0.791	0.382	0.305
C x M.F x Y	0.279	0.445	0.165	0.15	0.929	0.470	0.988	0.97	0.783	0.918	0.791	0.997	0.996
CV (%)	6	41.9	27.4	28.3	24.6	65.3	46.2	47.4	27.4	37	2.6	24.1	23.2

C = compost; M.F = mineral fertilizer

Appendix 2: Summary of analysis of variance of millet grain and straw yields and millet rainfall use efficiency

	P values		
Sources of variation	Grain yield	Straw yield	RUE
Compost	< 0.001	< 0.001	< 0.001
Mineral Fertilizer	< 0.001	< 0.001	< 0.001
Year	< 0.001	< 0.001	< 0.001
Compost x Mineral Fertilizer	< 0.001	0.004	< 0.001
Compost xYear	0.382	< 0.001	0.422
Mineral Fertilizer x Year	0.067	0.026	0.113
Compost x Mineral Fertilizer x Year	0.002	0.045	0.025
CV (%)	19.1	18.1	18.1

Appendix 3: Summary of analysis of variance of cowpea grain and haulm yields and cowpea RUE

	P values		
Sources of variation	Grain yield	Haulm yield	RUE
Compost	< 0.001	< 0.001	0.001
Mineral Fertilizer	0.008	0.149	0.235
Year	< 0.001	< 0.001	0.031
Compost x Mineral Fertilizer	0.533	0.102	0.305

Compost x Year	0.034	0.222	0.124
Mineral Fertilizer x Year	0.271	0.456	0.501
Compost x Mineral Fertilizer x Year	0.560	0.058	0.214
CV (%)	40.8	30.5	39