KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI, GHANA

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CROP AND SOIL SCIENCES

MINERAL NITROGEN AND MICROBIAL BIOMASS DYNAMICS UNDER MILLET GLUME COMPOST APPLICATION IN SEMI - ARID NIGER

BY

MAIMOUNA IDRISSA ALSO

(INGENIEUR AGRONOME)

JULY, 2014

MINERAL NITROGEN AND MICROBIAL BIOMASS DYNAMICS UNDER MILLET GLUME COMPOST APPLICATION IN SEMI - ARID NIGER

BY

MAIMOUNA IDRISSA ALSO

(INGENIEUR AGRONOME)

A Thesis submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, in partial fulfilment of the requirements for the award of the Degree of

MASTER OF SCIENCE

IN

SOIL SCIENCE

JULY, 2014

DECLARATION

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

Idrissa Also Maimouna	……………………..	………....................
(Student)	Signature	Date

Certified by:

Dr. Vincent Logah	……………………..	………....................
(Principal Supervisor)	Signature	Date
Dr. Nana Ewusi-Mensah	……………………..	………......................
(Co-supervisor)	Signature	Date

Certified by:

Dr. Charles Kwoseh	……………………..	……….......................
(Head of Department)	Signature	Date

ABSTRACT

Most farmers in Semi-arid Niger preferably apply composted millet straw to crop fields to enhance fertility status of their soils due to the escalating prices of mineral fertilizers. As a result of the competitive use of the straw, micro-dosing of millet glume compost is emerging as an alternative technology to enhance soil health. However, there is no systematic research on its impact on soil fertility indicators and crop yield. This study therefore aimed to bridge this gap in knowledge by providing relevant data / information on crop and soil response to micro-dose application of the millet glume compost (MGC) within the framework of integrated nutrient management. A field experiment was conducted in 2013 at N'dounga / Regional Centre for Agricultural Research of Niger (INRAN / CERRA / Kollo). The experiment consisted of the following treatments: 88 g urea + 500 g SSP (MF), 150 g MGC (C 150 g), 150 g MGC + 88 g urea + 500 g SSP (C 150 g + MF) 300 g MGC only (C 300 g), 300 g MGC + 88 g urea + 500 g SSP (C 300 g + MF) and a control (no amendment). The treatments were replicated three times in a randomized complete block design. The results indicated variations in microbial biomass C, N and P as well as NO_3^- -N and NH_4^+ -N over the sampling periods of the study. For example, microbial biomass C and N observed at 12 weeks after sowing (WAS) under the amendments were generally higher than values recorded at 4 WAS. Biomass C and N were significantly higher ($P > 0.05$) under the C 300 g + MF amendment than all other amended plots and the control. Biomass P values were low under all amendments at both periods of sampling (4 and 12 WAS). Biomass C showed significant correlation ($P < 0.05$) with NO_3^- ($r = 0.74$) and organic carbon ($r = 0.90$) whilst biomass N correlated significantly ($P < 0.05$) with NO_3^- -N ($r = 0.72$) and with total N ($r = 0.75$). Nitrate-nitrogen levels in the soil increased markedly from 8 WAS to 12 WAS indicating the occurrence of Birch effect. Comparatively, the levels of NO_3^- were generally higher than that of NH_4^+ at all sampling periods. This has implications for nitrogen loss from the soil system as nitrogen in the form of NO_3^- is subject to more leaching than NH_4^+ -N. Sole application of millet glume compost or in combination with mineral fertilizer led to increase in organic C and total N contents of the soil. Millet grain yield obtained under the sole or combined applications of MGC and mineral fertilizers were low due to erractic rainfall patterns. This notwithstanding, C 300 g + MF produced more grain yield than all the amendments. Crop harvest index ranged from 33.42 – 42.7% under the soil amendments. The study indicated that micro-dose rate of 300 g millet glume compost + 88 g urea + 500 g SSP (i.e. 3t/ha compost + 15 N kg/ha + 13 P kg/ha) is potentially ideal for crop growth and soil fertility improvement in Semi-arid Niger.

DEDICATION

This thesis is dedicated to my dear dad.

ACKNOWLEDGMENT

Writing this Thesis has been one of the most demanding academic challenges I have ever had to face. Without the support, patience and guidance of my husband Mahamadou Hamadou, my families, lecturers and colleagues, this study would not have been completed on schedule. It is to them I owe my gratitude.

To Dr. Vincent Logah and Dr. Nana Ewusi-Mensah who diligently supervised this work despite their many other academic and professional commitments, I say thank you.

Special thanks to AGRA for the scholarship which made this project a reality. I notably thank all the staff and workers at the Department of Crop and Soil Sciences, KNUST for their encouragement and moral support during the study period. Finally, to the staff and workers at INRAN and ICRISAT Soil Laboratory, Niger who assited me during the study period, thank you.

Table of Contents

CONTENTS
PAGE

LIST OF FIGURES

PAGE

LIST OF TABLES

PAGE

CHAPTER ONE

1.0 INTRODUCTION

Lack of moisture limits crop production in Semi-arid West Africa but poor soil fertility is a more serious constraint in the long run (Bationo and Mokwunye, 1991a). In the West African Semi-arid tropics (WASAT), continuous cultivation leads to drastically reduced levels of soil organic matter. Such reductions in the level of soil organic matter have resulted in decreased soil productivity (Bationo and Mokwunye, 1991b). Due to increased population pressure, farmers increasingly rely on agricultural soil, which they have learnt to rehabilitate with different technologies (Fatondji *et al.*, 2006) such as addition of mineral fertilizer and organic materials which have beneficial effects on the soils' chemical and physical properties (Bationo and Mokwunye, 1991b).

Millet is a fundamental cereal for many rural populations in Semi-arid zone of Africa. It is the sixth most consumed cereal in the world and an important food crop for food security in Niger (Idrissa, 2010). Trials conducted by researchers showed that millet yields can be increased by more than 250% by the use of fertilizers (Bationo and Mokwunye, 1991a). In the West African Sahel, farmers use crop residues and manure to reclaim degraded croplands. According to Addam *et al.* (2010), there was an increase of 26 – 71% in millet biomass with application of transported manure, chemical fertilizer or both compared to the non-application. They also reported that inorganic fertilizer appears to be the best means of restoring the nutrient imbalance, increasing crop yields and raising rural income. However, most rural farmers cannot afford the cost of mineral fertilizers. Researchers have therefore, proposed targeted application of organic amendments by the use of micro-dosing (Fatondji *et al.*, 2006).

Though some farmers in Niger have started using millet glumes compost (MGC) instead of composted millet straw for soil fertility management through microdosing, no systematic research has been done on the former. The use of millet glumes compost in crop production is an emerging practice in Niger and is yet to receive the needed research attention.

Nitrogen is the nutrient that is most frequently limiting to crop production and the nutrient applied in the greatest amounts (Campbell *et al.*, 1986). Given the widespread prevalence of nutrient stresses worldwide, a thorough understanding of acquisition, mineralization and dynamics of nutrients under varying cropping systems is essential (Ariharia, 2000). In an attempt to curtail the declining nitrogen contents of soils, many studies have focused on fates of nitrogen inputs during one or more growing seasons and many chemical and biological assays have been developed to predict nitrogen availability to crops (Bundy and Meisinger, 1994). However in sub-Sahara Africa, there is dearth of published information on the dynamics of mineral nitrogen under different (organic and inorganic) amendments on the field. Most studies focused on nitrogen mineralization under laboratory conditions, results of which may be of limited importance under field conditions (Logah *et al.*, 2011).

Soil microorganisms play an integral function in the cycling of nutrients within terrestrial ecosystems (Holmes and Zak, 1994). Verhoef and Brussaard (1990) reported that soil microorganisms can enhance decomposition and nutrient release, and hence ameliorate soil properties. There is virtually no research on the impact of

MGC on soil microbial biomass and mineral -N (NO_3^--N and NH_4^+-N) dynamics in Semi-arid Niger. This study aims to bridge this gap in knowledge by providing relevant information on the subject. Research on the dynamics of mineral -N and microbial biomass under MGC will help in sustainable soil fertility management and eventually increase productivity of cropping systems.

Working on the hypothesis that micro-dosing of millet glume compost and mineral fertilizer (N and P) application will significantly influence mineral -N and microbial biomass under millet cropping systems in semi-arid Niger, the objectives of this study were to:

i. evaluate the effect of millet glumes compost and mineral fertilizers on NH_4^+-N and NO_3^--N dynamics under millet cropping system.
ii. evaluate microbial biomass C, N and P under different application rates of the compost and mineral fertilizers under millet cropping system.
iii. examine the short-term impact of the applied compost on soil organic carbon and total nitrogen.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil nitrogen

Nitrogen in the air (78%) is the ultimate source of all soil nitrogen. It may enter the soil through rainfall, plant residues, nitrogen fixation by soil organisms, animal manures and commercial fertilizers and may be lost through plant removal, volatilization, leaching or erosion (Barbarick, 2014).

2.1.1 Forms of nitrogen in the soil

Nitrogen exists in a number of chemical forms and undergoes chemical and biological reactions (Barbarick, 2014). These include organic nitrogen, urea nitrogen, ammonium and nitrate nitrogen, etc.

2.1.1.1 Organic nitrogen

It comprises over 95% of the nitrogen found in soil (Barbarick, 2014). It originates from the soil organic matter from crop residues and animal dung. This form of nitrogen cannot be used by plants but is gradually transformed by soil microorganisms to ammonium (Barbarick, 2014).

2.1.1.2 Urea nitrogen

It is a form that the soil does not hold. It results from hydrolysis of NH_4^+ (ammonium), a transformation that is accompanied by great losses through volatilization up to 40% (Barbarick, 2014).

2.1.1.3 Ammoniacal or ammonium-nitrogen

It results from the combination of nitrogen (N) and hydrogen (H). Due to its positive charge, NH_4^+ binds to the clay-humus soil complex which limits the risk of in-depth leaching. Microbial activity transforms ammonium to nitrate - nitrogen in a warm and well-drained soil (Barbarick, 2014).

2.1.1.4 Nitric or nitrate-nitrogen

It is naturally formed by the combination of nitrogen (N) and oxygen (O). Nitrate-nitrogen (NO_3^-) is the principal form of nitrogen used and most available to plants. It is not attracted to soil clay and so leaches easily. Microorganisms in poorly aerated soil can use the oxygen from nitrate in place of that in the air and convert it to nitrogen gases (Barbarick, 2014).

2.1.2 Mineralization of nitrogen

Mineralization refers to the net release of mineral nitrogen with the decay of organic matter. In the soil, nitrogen can undergo a number of transformations (Barbarick, 2014). Net N mineralization is the outcome of two concurrent but opposite directed processes: gross N mineralization and gross N immobilization. The transformations of organic and mineral nitrogen through the mineralization and the immobilization processes are therefore the main driver of carbon and nitrogen change in soils (Mike *et al.*, 1994).

The greater part of nitrogen in the soil is present in organic forms that are unavailable for plant uptake. This nitrogen becomes available to plants through mineralization. According to Deenik (2006), the organic nitrogen contained in soil (organic matter) is converted into plant usuable inorganic forms (ammonium and rapidly converted to nitrate) as a result of microbial activity. At the same time, nitrogen is removed again by soil microorganisms (immobilization) and losses may occur in the atmosphere (denitrification) or by leaching (Verhallen and LeBoeuf, 2006).

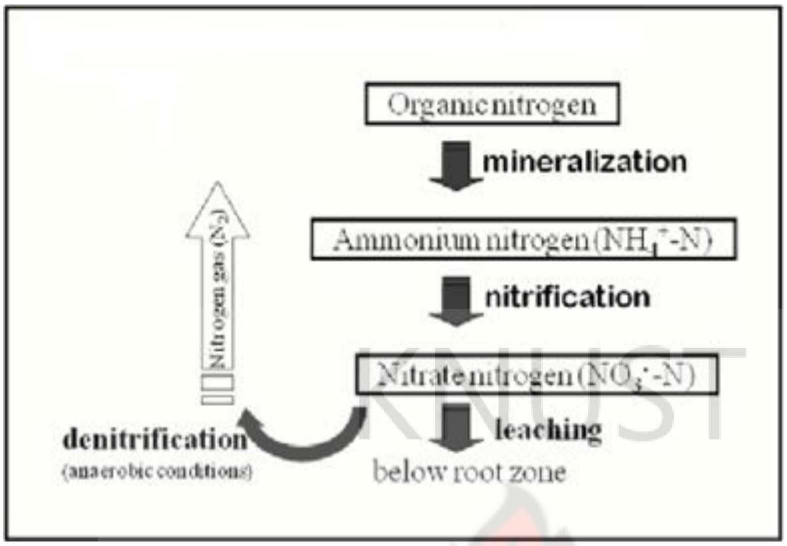

Figure 2.1. Nitrogen dynamics in the soil. (Source: Carol, 2007)

2.1.2.1 Factors affecting nitrogen mineralization

Among the factors controlling net N mineralization are organic compositions of the amendment and soil environment (Seneviratne *et al.*, 1998). Chemical composition can, to a certain degree, be controlled to increase the synchronization of nitrogen release with plant N demand, whereas climatic factors cannot be controlled and so must be taken into account when planning management measures (Dahlin *et al.*, 2005).

Work done by Deenik (2006) showed that soil temperature and moisture content have a strong effect on nitrogen mineralization reactions. Maximum nitrogen mineralization occurs when the soil temperature reaches 30-35 ^{O}C. In dry soils, N mineralization is low because soil microbial activity is limited by water availability. In saturated soils, lack of oxygen limits N mineralization because only soil microorganisms that can survive under anaerobic conditions are active (Deenik, 2006). MacDonald *et al.* (1995) found that accumulation of mineralized N increased with increasing temperature.

Soil texture has been reported to influence nitrogen mineralization (Franzluebbers *et al.*, 1996). The amount and type of clay in a soil affects N mineralization reactions. Soils dominated by clay minerals that shrink and swell with fluctuations in soil moisture tend to have higher N mineralization rates than those containing clays that do not shrink and swell (Deenik, 2006). Mineralizable carbon and nitrogen ratio decreases with increasing clay content (Franzluebbers *et al.*, 1996).

According to Breland and Hansen (1996), soil compaction reduces the proportion of large pore spaces and increases the relative proportion of small pore spaces. They indicated that nitrogen mineralization was negatively correlated with small soil pores. Medium size pores allow microbes' access to organic matter and retain water under dryer conditions (Strong *et al.*, 1999). Thus, medium size pores are the most important to mineralization and their loss under soil compaction is most serious (Strong *et al.*, 1999).

Decomposition and subsequent release of N from an amendment is dependent on its quality or chemical composition (Heal *et al.*, 1997). The relative amounts of C to N in the organic matter exert a considerable influence on the available N status of the soil. Kirchmann *et al.* (2002) reported that straw residues frequently have a wide C/N ratio and when incorporated into the soil can bind quite large amounts of nitrate.

2.2 Functions of nitrogen in plants growth

Nitrogen is a vitally important plant nutrient (Adediran and Banjoko, 1995; Shanti *et al.*, 1997). In crop production it is a major yield-determining factor and its availability in sufficient quantity throughout the growing season is essential for optimum crop growth (Kogbe and Adediran, 2003).

In plant nutrition, nitrogen is involved in the composition of chlorophyll and protein. It stimulates the growth and development of all tissues and improves the quality of leafy vegetables, forages, and the protein content of cereals (Mills and Jones, 1996). An adequate supply of N is associated with vigorous vegetative growth and a dark green colour. An imbalance of N or its excess in relation to other nutrients such as P, K, and S can prolong the growing period, delay crop maturity and increase sensitivity to diseases especially in case of lack of potassium and phosphorus (Marti and Mills, 1991). Nitrogen deficiency causes stunting and yellowing of plants. This yellowing or chlorosis, usually appears first on the lower leaves; the upper leaves remaining green. In cases of severe N shortage, the leaves will turn brown and die (Mills and Jones, 1996).

2.3 The role of other essential nutrients (phosphorus and potassium) in plant nutrition

2.3.1 Phosphorus

Phosphorus (P) is the most important nutrient element (after nitrogen) limiting crop production in most regions of the world (Holford, 1997; Kogbe and Adediran, 2003). Internally, most crops need 0.2 to 0.5% P in the dry matter for normal growth (Gabriel, 2010). Phosphorus is involved in protein formation. It improves earliness and plant fertility and stimulates root growth.

Plants extract P exclusively from the soil solution in either $H_2PO_4^-$ or HPO_4^{2-} form. It is estimated that much as 90% of added fertilizer phosphorus is fixed in soils (Potash and Phosphate Institute, 2003). Generally, phosphorus in all its natural forms, including organic forms is very stable or insoluble and only a small proportion exists in the soil solution at any one time (Holford, 1997). Soil phosphorus fixation is minimized when soil pH is maintained between 6 and 7.

Phosphorus-deficient plants are stunted with a limited root system and thin stems. In many plants, seedlings look stunted and older leaves may turn purple and grain yield often severely reduced (Jones *et al.,* 2003). Phosphorus deficiency also causes green-dark blue color starting with the older leaves and delayed maturity or infertility (Sagna and Marchal, 1992).

2.3.2 Potassium

Potassium (K) is needed in large quantities by many crops (Hue, 1995). In soils, potassium is quite mobile as compared to phosphorus. It exists as K^+ in soil solution and is absorbed by roots in that form. It is involved in water uptake from the soil, and its retention in the plant tissue and long distance transport of water (Marschner, 1995). If K is not taken up by plants, it may be lost through leaching (Bergmann, 1992; Perrenoud, 1993; Singh and Trehan, 1998). One way to reduce K leaching is to add organic matter such as compost to the soil.

Potassium has a catalytic effect in the physiological functions of the plant. It promotes the synthesis of carbohydrates and their accumulation in storage organs (tubers, root, etc.). It promotes resistance to drought, disease and lodging. Potassium increases grain size and improves the quality of fruits and vegetables (Bergmann, 1992). K-deficient plants show low resistance to diseases and their seeds and fruits are small and shriveled (Martin-Prevel, 1989; Perrenoud, 1993). The most visual K deficiency symptom is the scorching or firing along leaf tips and margins

(Bergmann, 1992; Perrenoud, 1993; Singh and Trehan, 1998). Potassium deficiency also causes sensitivity to lodging and chlorosis (Sagna and Marchal, 1992).

2.4 Nutrient depletion and replenishment under cropping systems

As populations grow, soil-nutrient capital is gradually depleted when farmers are unable to sufficiently compensate losses by returning nutrients to the soil via crop residues, manures and mineral fertilizers (Gabriel, 2010). Increasing pressures on agricultural lands result in much higher nutrient outflows and the subsequent breakdown of many soil fertility maintenance strategies (Sanders *et al.*, 1996). Several decades of nutrient depletion have transformed originally fertile lands that yielded about 2 to 4 t ha^{-1} of cereal grain into infertile ones where cereal crops yield less than 1 t ha^{-1} (Roland *et al.*, 1997)

The bulk of the food in Africa is produced on smallholder farms (Cleaver and Schreiber, 1994; Gladwin *et al.*, 1997). One of the major problems affecting food production in Africa is the rapid depletion of nutrients in smallholder farms (Badiane and Delgado, 1995). This is because the smallholder farmer is poorly resourced and unable to invest in soil fertility inputs, particularly mineral fertilizers (Gabriel, 2010). The major effect of soil fertility decline is the observed reduced food production in most African countries (Gabriel, 2010). In order to sustain soil and crop productivity, it is necessary to explore alternative soil fertility replenishment strategies, which are effective and affordable to farmers, especially the smallholder farmer (Gabriel, 2010).

The major pathways of soil fertility depletion on farmlands include loss of nutrients through erosion, leaching, volatilization, crop uptake and harvest without the complementary replenishment (Gabriel, 2010). Soil nutrient replenishment is therefore a prerequisite for halting soil fertility decline (Munyabarenzi *et al.*, 2012). This may be accomplished through the application of mineral and organic fertilizers (Munyabarenzi *et al.*, 2012). In Niger, the most deficient nutrients in soils are nitrogen and phosphorus. Nitrogen inputs at the field scale mainly come from inorganic fertilizers, biological nitrogen fixation (BNF), animal manures or composts produced and nitrate capture from subsoil depths beyond the reach of crop roots (Gabriel, 2010).

Inorganic fertilizers do not contain C sources, and therefore much of the fertilizer N not used by crops is subject to leaching and denitrification losses (Sanchez, 1997). Organic additions therefore apparently provide the C necessary to reduce the depletion of N in fertile soils (Sanchez, 1997). Soil microorganisms need a C substrate for growth and energy. They utilize the N from organic inputs. The joint organic-inorganic N replenishment strategy provides both N and C inputs that gradually increase soil N and C stocks (Buol and Stokes, 1997).

Phosphorus replenishment is usually accompanied by nitrogen replenishment because most P-deficient soils are also deficient in N (Sanchez, 1997). Potassium deficiencies do occur in specific circumstances, but not to the same extent as N and P deficiencies (Gabriel, 2010). Soil productivity can be sustained through integrating mineral fertilizers application with organic inputs (manure, composts and plant residues) and this is the most effective means of replenishing soil nutrients (Gabriel, 2010).

2.5 Soil fertility management options

2.5.1 The use of mineral fertilizers

Mineral fertilizer is a major entry point to increase yields. Throughout Africa, however, sufficient mineral fertilizers are not available at the right time during the year. Fertilizer shortage is mainly attributable to the high transaction costs (Quinones *et al.,* 1997). Moreover, the little fertilizer available is often not the correct type required for various crops, and farmers are unfamiliar with its correct usage (Sanginga and Woomer, 2009). Fertilizer adulteration is not uncommon in several African countries, and discourages fertilizer investment by farmers (Sanginga and Woomer, 2009). In Africa, the average fertilizer recommendation rate is around 50 kg/ha. In most cases however, the farmers using the inorganic inputs hardly use the recommended rates with most of them applying less than 20 kg N/ha (Adiel, 2004).

2.5.2 The use of organic fertilizers

Organic inputs are often proposed as alternatives to mineral fertilizer. Organic fertilizers provide nutrients to plants and add organic matter to the soil.

The main sources of organic fertilizers are crop residues (millet, sorghum and maize straw, groundnut haulm) as well as other plant residues, green manure (fallow vegetation), animal manure (from cattle, sheep or goat) and other organic residues, composted or noncomposted (Fatondji, 2002; Fatondji *et al.,* 2009). In the Sahelian zone of West Africa, where farmers use very little or no inorganic fertilizers because of their high cost (McInter, 1986), organic fertilizers constitute the principal source of nutrients for sustainable agriculture. Farmers in Niger use crop residues as an integral component of soil fertility management practices. The availability of organic resources as nutrients sources is limited by their alternative uses as fuel, feed and fiber (Sanchez *et al.,* 1997). Composting is a practical means of bulking organic resources for concentrating their nutrients for plant use.

2.5.3 The combined use of mineral fertilizer and organic materials

Donovan and Casey (1998) reported that combination of mineral fertilizers with organic nutrient sources can be considered as better options for increasing fertilizer use efficiency as a result of improved synchronization of nutrient release and uptake by the crops (Palm *et al.,* 1997). Whereas fertilizers release their nutrients rather rapidly, manure and crop residue act as slow-release fertilizers (Pierre *et al.*, 2008). A judicious combination of organic and mineral sources of nutrients is therefore promoted as it addresses both the problem of insufficient fertilizer supply and the large amounts of organic material required for nutrients supply (Pieri, 1989; Palm *et al.,* 1997; Bationo and Buerkert, 2001). Efficient use of both organic and inorganic fertilizers is required to optimize crop yield to meet the food needs of a growing population and minimize soil degradation (Pieri, 1989; Palm *et al.,* 1997; Bationo and Buerkert, 2001).

It is important to combine organic and mineral sources of nutrients to obtain the full advantage of both sources (Giller, 2002). Combining mineral fertilizer and organic inputs can substantially improve the agronomic efficiency of the nutrient use compared to the same amount of nutrients applied through either source alone (Vanlauwe *et al.,* 2001).

2.5.4 Fertilizer micro-dosing

Micro-dose fertilization technology aims at applying small amounts of inorganic fertilizers in planting pits to increase yields while reducing investment in fertilizer

(Tabo *et al*., 2005a). Fertilizer micro-dosing helps to improve and stabilize production and farmers' incomes (Tabo *et al.*, 2005b).

The technology has been applied in three countries in West Africa (Burkina Faso, Mali, and Niger) between 2002 and 2004 for the dissemination of the strategic application of fertilizer per pocket on millet crops and sorghum. The above selected countries are characterized by predominantly sandy soils with low fertility status. Demonstrations conducted on the technology in the three countries showed a considerable improvement in millet and sorghum responses to micro-doses of fertilizer (Tabo *et al.*, 2005b).

2.6 Composting

Many studies have demonstrated that application of manure will produce crop yields equivalent or superior to those obtained with chemical fertilizers (Xie and MacKenzie, 1986; Motavalli *et al.*, 1989). Manure improves the physical condition of the soil and increases biological activity (Sommerfeldt and Chang, 1985; Chang *et al*., 1990; CAST, 1996). William *et al.* (1995) indicated that there was not enough manure to sustain yields at even the levels found in farmers' fields. Bationo and Mokwunye (1992) also noted that the addition of organic materials either in the form of manures or crop residues has beneficial effects on the soil's chemical and physical properties. Compost is a slow-release fertilizer. Compared with fresh manure, its N is in a more stable form and not susceptible to loss as NH_3 gas (Leonard, 1986). The nutrient value of compost varies a lot and depends on what it is made from. In the preparation of compost, it is desirable to mix materials in the proportions that give rapid, effective and complete decomposition to a stable product (Harris *et al.*, 2001).

Organic materials such as crop residues, animal manure, food scraps, some municipal wastes and appropriate industrial waste, can be applied to land as fertilizer, once the composting process is completed (Misra *et al.*, 2005). Composting is a useful method of producing a stabilized product that can be stored or spread with little odour. The other advantages of composting include killing of pathogens and weed seeds, and improving handling characteristics of organic materials by reducing their volume and weight. However, composting has some disadvantages that include nutrient and C loss during its preparation and the associated labour cost (Eghball, 2002).

Compost is an important source of organic matter. The soil organic matter plays an important role in sustaining soil fertility for sustainable agricultural production. In addition to being a source of nutrients for crops, organic matter improves the biological and physico-chemical properties of the soil. Following these improvements, the soil becomes more resistant to stresses such as drought, disease and toxicity (Misra *et al.*, 2005). The stability and quality of compost play a significant role in the evolution of the soil microbial biomass (Jedidi *et al.*, 2004).

2.6.1 Factors affecting composting

For the success of composting, the observation of a number of parameters is required:

2.6.1.1 Temperature

Heat is an important byproduct of bacterial activity. The process of composting involves two temperature ranges: mesophilic and thermophilic. High temperatures characterize the composting process and serve as signs of vigorous microbial activities (Ezennia, 2011). As an added benefit, exposure to high temperatures helps kill disease-causing microorganisms (pathogens), thereby helping to reduce the risks of disease transmission from infected materials. Pathogens are normally destroyed at 55 °C and above, while the critical point for elimination of weed seeds is 62 °C. Turnings and aeration can be used to regulate temperature (Misra *et al.,* 2005). Temperature monitoring is an indirect measure of the intensity of the decomposition. It also provides information on the quality of the degradation process (Misra *et al.*, 2005).

2.6.1.2 Humidity

Many factors affect the composting process, but moisture content often is the most crucial. The compost should be moist but not soggy (Rynk *et al.*, 1992). Moisture is necessary to support the metabolic activity of the micro-organisms (Misra *et al.*, 2003). Composting materials should maintain a moisture content of 40-65% (Misra *et al.,* 2003). Where the pile is too dry, composting occurs more slowly, while a moisture content in excess of 65% develops anaerobic conditions (Misra *et al.*, 2003). In practice, for optimum performance, it is advisable to start the pile with a moisture content of 50-60%, finishing at about 30% (Misra *et al.*, 2003) as this enhances microbial activity. Scott (1957) showed that actively growing fungi require a relative humidity above 75%, while most bacteria require more than 95% moisture (Bationo, 2008).

2.6.1.3 Oxygenation

Although organic decay readily occurs under anaerobic conditions, the term composting refers to aerobic decay processes (Misra *et al.,* 2003). In most cases, aerobic microbial activity is considered more desirable than anaerobic decay. Aerobic composting requires large amounts of oxygen, particularly at the initial stage

(Mustin, 1987). To keep a composting process sufficiently aerobic, oxygen concentrations of at least 5% within the compost is recommended (Mustin, 1987). Aeration is the source of oxygen, and, thus, indispensable for composting (Misra *et al.*, 2003). Where the supply of oxygen is not sufficient, the growth of aerobic microorganisms is limited, resulting in slower decomposition (Misra *et al.*, 2003). Moreover, aeration removes excessive heat, water vapour and other gases trapped in the pile (Misra *et al.*, 2003).

Since highly active aerobic microorganisms use oxygen rapidly, maintaining aerobic conditions throughout a compost pile, requires constant monitoring and may be achieved by controlling the physical quality of the materials (particle size and moisture content), pile size and by ensuring adequate frequency of turning (Misra *et al.*, 2005).

2.6.1.4 pH

It is an indicator of the degree of biological and biochemical decomposition. Although the natural buffering effect of the composting process lends itself to accepting materials with a wide range of pH, the pH level of the compost varies between 5 and 9 and should not exceed 8 (Bationo, 2008). At higher pH levels, more ammonia gas is generated and may be lost to the atmosphere (Morel *et al.*, 1986; Bationo, 2008).

2.6.1.5 C / N ratio of organic materials

The optimal C / N ratio of raw materials for composting is normally between 25:1 and 30:1 although ratios between 20:1 and 40:1 are also acceptable (Bationo, 2008). Decomposition will occur, although more slowly, when C / N ratios are as low as 20:1, or as high as 40:1. Where the ratio is higher than 40:1, the growth of microorganisms is limited and causes slow decay, resulting in a longer composting time (Bationo, 2008). A C / N ratio of less than 20:1 leads to underutilization of N and the excess nitrogen in the mixture may be lost to the atmosphere as ammonia or nitrous oxide, and odour can be a problem. The C / N ratio of the final product should be between about 10:1 and 15:1 (Bationo, 2008).

One of the most common practices is to add inorganic fertilizers, particularly N, in order to modify a high C / N ratio. Similarly, P is sometimes applied as the C / P ratio of the material mix is also considered important (Mustin, 1987; Beck, 2008).

2.6.1.6 Lignin and polyphenol content of composting material

Lignin is one of the main constituents of plant cell walls, and its complex chemical structure makes it highly resistant to microbial degradation (Richard, 1996). This nature of lignin has two implications. Firstly, lignin reduces the bioavailability of the other cell-wall constituents, making the actual C / N ratio lower than the one normally cited (Ezennia, 2011). Secondly, lignin serves as a porosity enhancer, which creates favourable conditions for composting (Ezennia, 2011). Therefore, while the addition of lignin-decomposing fungi may in some cases increase available C, accelerate composting and reduce N loss, in other cases it may result in a higher actual C / N ratio and poor porosity, both of which prolong composting time (Misra *et al.*, 2003; Ezennia, 2011).

Polyphenols include hydrolysable and condensed tannins (Schorth, 2003). Insoluble condensed tannins bind the cell walls and proteins and make them physically or chemically less accessible to decomposers (Misra *et al.*, 2005). Soluble condensed and hydrolysable tannins react with proteins and reduce their microbial degradation and thus N release (Misra *et al.*, 2003). Polyphenol and lignin are attracting more attention as inhibiting factors to decomposition (Misra *et al.,* 2003). Palm *et al.* (2001) suggested that the contents of these two substances be used to classify organic materials for more efficient on-farm natural resource utilization, including composting.

2.6.1.7 Microorganisms

Microorganisms are normally present in the compost. Rapid composting presupposes that a large, active microbial population is present. While some composters find improved aeration enough for enhanced microbial activities, others may need inoculation of microorganisms (Misra *et al.*, 2003). The inoculum are an affordable choice for those with access to the market and also for resource-poor farmers (Misra *et al.,* 2005). The production cost could be reduced by using inoculum taken from compost pits, by purchasing the commercial product and multiplying it on the farm, and by utilizing native inoculum derived from soils or plant leaves (Misra *et al.,* 2003). Inoculating compost with material from a previous compost pile can be beneficial, because it adds a representative mix of microorganisms in high numbers (Coyne, 1999).

2.6.2 Qualities of a good compost

Compost quality can be assessed from its agronomic characteristics, health and polluting properties. Agronomically, it is related to its nutrient content (N, P, and K) and organic matter (Waas, 1996; Bationo, 2008), which gives it a fertilizer value and soil amending power.

The compost may also be characterized in terms of its acidity. The pH is a factor that determines the availability of nutrients for microorganisms, the solubility of heavy metals and most biochemical reactions (Soudi, 2001; Bationo, 2008). Therefore, it provides information on the degree of base saturation of the compost (Bationo, 2008).

The chemical characteristics of good compost according to AFNOR (French Association of Normalization) and FAO standards are shown in Table 2.1.

Table 2.1. Different quality standards for compost

Total nutrients	AFNOR standard	FAO standard
Organic matter (%)	> 5	10 – 30
Nitrogen (%)	> 0.25	0.4 – 0.5
Phosphorus (%)	> 0.3	0.1 – 1.6
Potassium (%)	> 0.1	0.4 – 2.3
C/N ratio	20	15 – 20

Source: Soudi (2001)

2.7 Effect of compost application on nitrogen mineralization

Application of organic fertilizer has received great attention because of its direct and indirect effects on crop growth and yield as well as soil properties. Organic amendments may affect the amounts and percentage distribution of organic N forms in whole soils (Nguyen and Shindo, 2011). A number of authors have studied the influence of different types of organic fertilizer on the amounts and properties of N (Nguyen and Shindo, 2011). Tanaka and Shindo (2009) found that long-term compost application increased the amount of N to a large extent. On the other hand, several authors have observed positive effects of different levels of organic amendments on soil properties. For example, soil organic matter content, total N content and soil microbial population increased with increasing the rate of compost application (Chang *et al.,* 2007; Sodhi *et al.,* 2009). However, the effect of amendments on the contents and distribution of forms of organic N and the relationship between the amounts of amendment and organic N forms have received little attention (Nguyen and Shindo, 2011).

Understanding how the quality of organic soil amendments affects nitrogen (N) mineralization and plant N uptake is critical for optimal agronomic N management and environmental protection (Loecke *et al.,* 2012). Composting manures prior to soil application has been reported to increase soil N. Improved understanding of how soil management and organic amendments application influence N mineralization is critical for optimizing N synchrony, but few studies to date have simultaneously measured the different components of N synchrony (Loecke *et al.,* 2012). Soil N mineralization and immobilization are tightly regulated by the relative demand for organic C and N by soil microbes (Hadas *et al.,* 1996). Composted plant materials and animal manure have long been used to improve soil fertility, although in practice composting can have mixed effects on net N mineralization (Shi *et al.,* 1999; Cambardella *et al.,* 2003). Application of composted manure produces greater net N mineralization (Loecke *et al.,* 2012). Other reports of net N mineralization following application of composted manures indicate variable inter-annual responses (Ma *et al.,* 1999; Eghball, 2000).

Nitrogen mineralization depends on application method, kind of organic matter, microbial activity, aeration and moisture. In dry soils with aerobic condition, ammonification occurs faster than the oxidation of ammonium to nitrate, resulting in a minimum nitrate accumulation (Linca *et al.,* 2012). In their study, Linca *et al.* (2012) found a positive net N mineralization from goat manure and straw compost.

The application of biowaste and vegetable waste composts increases soil organic matter and total N content (He *et al.*, 1992; Crecchio *et al.*, 2001; Nevens and Reheul, 2003; Hartl and Erhart, 2005). Increasing the N use efficiency of organic amendments and understanding the N dynamics in compost amended soils remain important issues for research (Amlinger *et al.*, 2003; Gutser *et al.*, 2005). Compost addition to soils was shown not to increase mineralization of soil organic matter (Sikora and Yakovchenko, 1996). In general, N availability from composts to plants is low since the majority of the total compost N is bound to the organic N pool (Amlinger *et al.*, 2003; Gutser *et al.*, 2005; Hartl and Erhart, 2005). This is also due to the fact that the mineral nitrogen content of composts is generally low, as N is partly lost during composting through volatilisation (Zwart, 2003). Iglesias-Jimenez and Alvarez (1993) showed that composts with C / N ratio < 12 can result in net N mineralization. Research on N mineralization has shown that there is a strong relationship between C / N ratios of various types of organic materials and the resulting N mineralization (Chadwick *et al.*, 2000; Chaves *et al.*, 2004). The more recalcitrant the carbon source to decomposition, the slower the N mineralization (Janssen, 1996; Rogers *et al.* 2001). Compared to sewage sludge, biosolids, manures, or other non-composted organic amendments, compost application results in lower N mineralization rates (Petersen, 2003; Gutser *et al.*, 2005). Han *et al.* (2004) demonstrated that a combined application of compost with chemical fertilizer could improve the compost use efficiency by increasing mineralization of compost N, especially in soils with low mineral N content.

2.8 Soil microbial biomass

Soil microorganisms play an integral function in the cycling of N within terrestrial ecosystems. The microbial biomass is the labile and the active fraction of soil organic matter (Horwath and Paul, 1994). Temporal variation in rates of N transformations results from seasonal changes in factors such as soil temperature, water potential and C availability controlling microbial activity (Holmes and Zak, 1994). Several studies suggest that seasonal variation in microbial biomass corresponds to variation in soil water potential and substrate availability (Clarholm and Rosswall, 1980; Singh *et al.*, 1989; Srivastava, 1992).

Few studies, however, have investigated the seasonal variation of microbial biomass (Groffman and Tiedje, 1989). As a consequence, it is uncertain whether microbial biomass varies or remains constant during the growing season (Holmes and Zak, 1994). Microbial activity within the soil is thought to be most limited by C inputs (Smith and Paul, 1990).

Under conditions of increased substrate availability, microbial populations could increase, provided that soil temperature and water potential do not limit growth. According to Holmes and Zak (1994), microbial population increases and rates of net N mineralization decline as N is assimilated to form new microbial biomass.

The method used to evaluate the soil microbial biomass consists of measuring the carbon (or the nitrogen and phosphorus) it contains. Most of the techniques currently available cannot give absolute values and reliable results. However, the most used technique is the fumigation-extraction, which uses chloroform vapor (Wu *et al.*, 1990).

2.9 Effect of compost application on soil microbial biomass

The biological component of the soil is responsible for soil humus formation, cycling of nutrients and building soil tilth and structure along with many other functions (Lynch, 1983; Wood, 1991; Kennedy, 1999). The application of compost increases the percentages of organic matter, nutrient levels (providing a slow fertilization action over a long period of time), microbial biomass and improves the soils' physical properties (Ribereau-Gayon and Peybaud, 1982; Bertran *et al.*, 2004). Various studies have examined the effects of different organic matters on microbial biomass of soil. Previous studies have found that amendment with farm-yard manure (Toyota and Kuninaga, 2006), grape compost (Saison *et al.*, 2006) and spent mushroom compost (Perez-Piqueres *et al.*, 2006) significantly affected soil microbial community structure (Carrera *et al.*, 2007). However, the effects of compost were found to vary depending on both the type of compost and the soil type (Pérez-Piqueres *et al.*, 2006). Microbial biomass increased with the quantity of compost added to the soil (Kim *et al.*, 1997). In the study of Saison *et al.* (2006), fungal biomasses in the soil per compost mixtures were enhanced following the addition of compost. Results from the study of Arslan *et al.* (2008) showed that kitchen waste compost perfectly increased the numbers of total bacteria.

Application of manure and compost on agricultural lands has been shown to positively increase and enrich soil food web (bacteria, fungi, protozoan and nematode density) and also affect a number of soil characteristics, including SOM, and soil respiration (Lundquist *et al.*, 1999; Ferris *et al.*, 2004; Carrera *et al.*, 2007; Treonis *et al.*, 2010).

Soil microbes typically are C-limited (Smith and Paul, 1990). Thus, with the addition of compost, a rapid increase in microbial activity and soil respiration occurs due to increased carbon reserves. Fliebach *et al.* (2007) also reported higher basal respiration in organically managed production systems when compared to unfertilized control plots. A number of studies have compared soil respiration, microbial biomass, and other microbial properties among contrasting management systems and reported significant differences (Lundquist *et al.,* 1999; Bulluck *et al.*, 2002; Bending *et al.*, 2004).

Increase in the quantity of organic inputs often result in high microbial biomass (Fliebach and Mäder, 2000). Organic farming systems with compost applications had 34% higher microbial biomass than treatments which did not receive any manure amendments (Fliebach *et al.,* 2007). With the addition of cover crops and compost, more organic matter is added which facilitates rapid microbial population growth. Compost application increased microbial biomass and had a positive impact on soil microbial functional diversity (Ajay and Mathieu, 2012). The results highlight higher microbial activity in soils receiving yearly compost applications (Ajay and Mathieu, 2012). Compost application can also indirectly increase nutrient availability by increasing microbial activity and abundance (Pascual *et al.,* 1997; Annabi *et al.*, 2007).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of experimental site

3.1.1 Location

The study was a field experiment conducted at N'dounga / Regional Centre for Agricultural Research of Niger (INRAN / CERRA / Kollo) (Fig. 3.1). N'dounga is located on longitude 2^0 18' 28" East and latitude 13^0 25' 00" North and is 30 km South-East of Niamey, capital of Niger. The laboratory analyses were conducted at ICRISAT Soil Laboratory in Niger.

3.1.2 Climate

The study area is located within the Soudano-Sahelian zone of Niger, characterized by two distinct seasons: rainy season (from June to October) and a long dry season (from November to May). The rainfall regime is characterized by a high variability both in time and in space, adversely affecting agricultural production. The rainfall patterns have battances of rains or storms in which large amounts of water can be recorded in relatively a short time. The average annual rainfall for ten years (2003-2012) is 510 mm. Temperatures vary according to time of the year. The lowest (23 °C) is recorded between October and February and the highest (45 °C) between March and June.

3.1.3 Soils

Three soils types are generally found in the study area (INRAN, 2012): hydromorphic soils and Vertisols located in the valleys (including river valley) which are mostly potentially fertile soils; highly leached tropical dune soils (Arenosol

WRB) with low organic matter content which occupies the majority of the zone; and the plateau soils, typically laterites and rigosols containing little organic matter.

This study was conducted specifically on the second type of soil which is better suited for crops such as millet, cowpea and sesame.

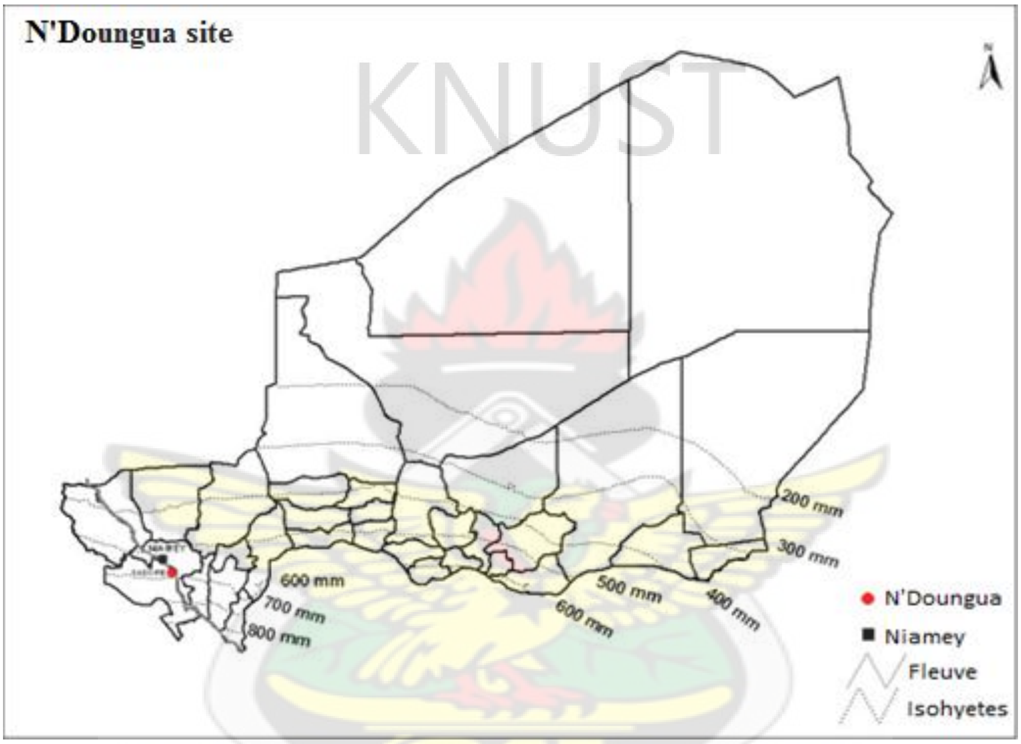

Figure 3.1. Location of the experimental site (Source: INRAN, 2012)

3.2 Field experiment

The field experiment was carried out to study the fertilizing effect of millet glume compost on soil properties and millet yield. The compost was applied alone (micro-dosed) and in combination with mineral fertilizers.

3.2.1 Crop cultivar used

Improved early flowering millet cultivar *Haini Kiré Precose* (HKP) obtained from recombination of Haini Kirey of Tera (Niger) since 1974 by INRAN was used as the test crop in the study. The cultivar gave good germination percentage of 95 percent.

3.2.2 Land preparation and sowing

The experimental field was ploughed to a depth of 15 cm, using a disc plough after which the field layout was done. Plot sizes measuring 6 m by 4.5 m were demarcated. A measure of three fingers of seeds were sown per hill and thinned to three plants per hill two weeks after sowing.

3.2.3 Experimental design / treatments

The field was laid out in a randomized complete block design (RCBD) with three replications. Each replication consisted of 6 plots measuring 4.5 m × 6 m (27 m^2) giving a total of 18 plots for the entire experiment. There were 1 m alleys between plots and 2 m between replications (Fig. 3.2).

The treatment combinations were 3 levels of compost × 2 levels of mineral fertilizers. The treatments (amendements) were as follows:

Control = Compost 0 g/ hill + 0g Urea and 0g Single Super Phosphate (SSP)

MF = 88 g Urea and 500 g SSP

C 150 g = Compost 150 g/ hill

C 150 g + MF = Compost 150 g/ hill + 88 g Urea and 500 g SSP

C 300 g = Compost 300 g/ hill

C 300 g + MF = Compost 300 g/ hill + 88 g Urea and 500 g SSP

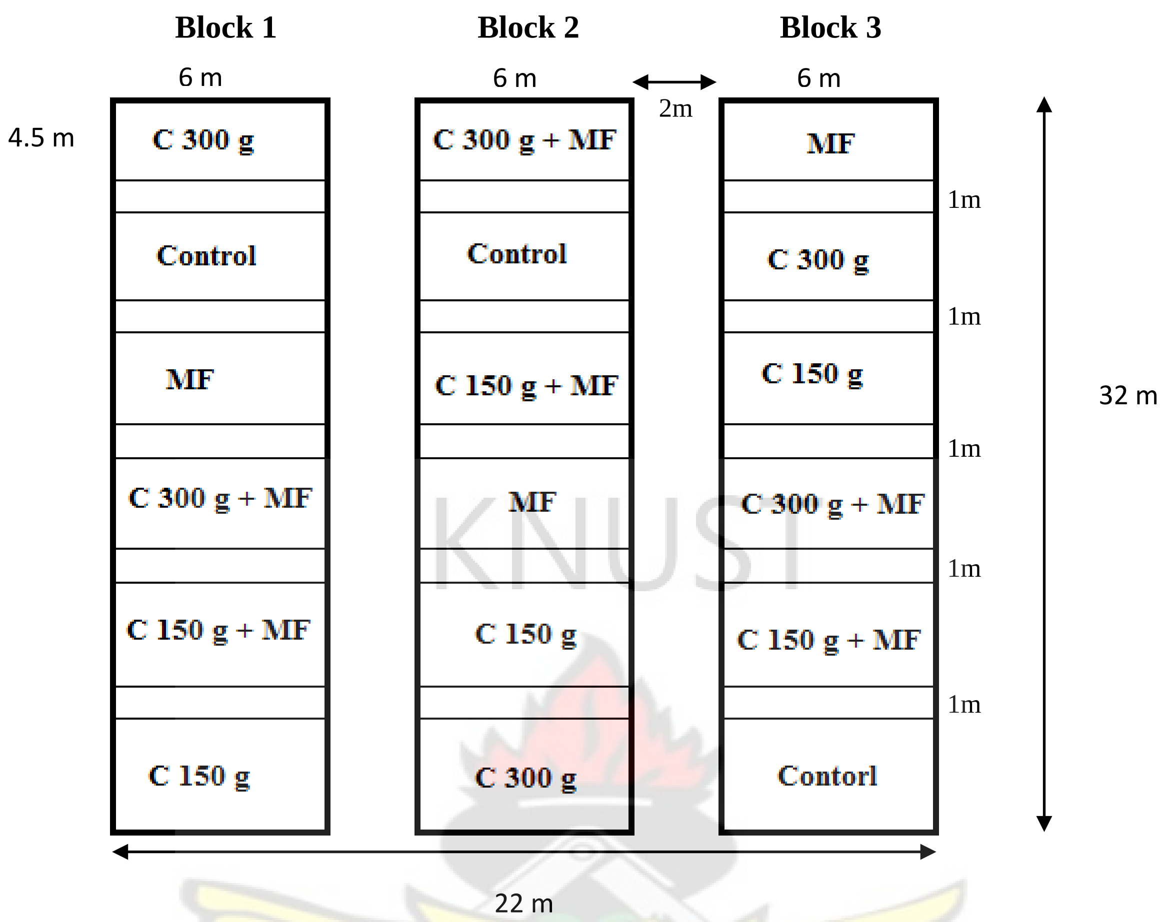

Figure 3.2. Field layout showing treatment allocations

3.2.4 Crop husbandry practices

The compost was applied at the same time of sowing seeds. It was applied in a pit dug by micro - dosing method. The urea was applied (broadcast) in two splits: four weeks and eight weeks after sowing. The SSP was applied (by broadcasting) at the time of sowing. Weed control was carried out with hoe and by hand picking.

3.3 Composting

3.3.1 Materials used for composting

The following principal materials were used:

- Millet glume and cattle manure (2:1 ratio)
- Ash (1/4 of all main materials)
- Urea

3.3.2 Compost preparation

Weights of manure and plant materials used were taken on dry weigh basis. Plant materials were reduced (chopped) to lengths of 5 – 10 mm, weighed and mixed prior to composting. Using the pit method, compost pits measuring 250 cm × 150 cm × 60 cm were dug and covered with black plastic sheets and soil to minimize water loss. The soil also acted as a bio-filter to minimize odour emission. Inoculum from fresh manure and urea was incorporated after fifteen days. The moisture content of each pit was maintained at 50 – 60% throughout the composting process. Temperature and pH of the compost were monitored at 0, 1, 2, 4, 6, 8, 10 and 12 weeks of maturation using a mercury thermometer and a glass electrode pH meter, respectively. Composting was done under a shade at the Research Station (CERRA – Niamey, INRAN) and harvested after 100 days of composting.

3.3.3 Compost characterization

Triplicate samples of 150 g were collected at the end of the composting process. The compost samples were air-dried and ground. Sub-samples were then taken using a spatula sterilized in 70% alcohol. The spatula was used to mix the compost slightly and to transfer samples into sterile containers and sealed tightly before being taken for laboratory analysis. Organic carbon, total nitrogen, phosphorus, potassium and magnesium contents were determined and used to assess the quality of the millet glume compost. Prior to composting, the millet glume was also characterized to establish its nutrient composition.

3.3.3.1 Organic carbon

Organic carbon content of millet glume compost was determined using the dichromate oxidation method. Ten millilitres of concentrated sulphuric acid, 10 ml 1.0 *M* $K_2Cr_2O_7$, and 10 ml of concentrated orthophosphoric acid were added to 0.05 g of compost sample in Erlenmeyer flask. The solution was allowed to stand on an asbestos sheet for 30 minutes after addition of distilled water. It was then back titrated with 1.0 *N* $FeSO_4$ solution with diphenylamine indicator.

Calculation:

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

where:

m.e. = normality of solution × ml of solution used

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

1.32 = correction factor

3.3.3.2 Nitrogen

Total N was determined by the Kjeldahl distillation and titration method in which millet glume compost was oxidized by sulphuric acid and hydrogen peroxide with selenium as catalyst. A 0.2 g sample was weighed into a Kjeldahl flask and a 10 ml concentrated sulphuric acid and selenium mixture (as catalyst) were added. The resulting mixture was digested for 3 hours until it became colourless. The clear digest obtained was transferred into a 50 ml conical flask and made to the mark with distilled water. A 5 ml aliquot of the sample and a blank were pipetted into the

Kjeldahl distillation apparatus. To this, 10 ml NaOH solution was added followed by distillation. The distillate was collected in boric acid and titrated with 0.1 *M* HCl using bromocresol green-methyl red as indicator (Okalebo *et al.*, 1993).

Calculation:

$$\% \text{ N} = (14 \times (\text{A - B}) \times \text{N} / 1000 \times \text{w}) \times 100$$

where:

A = ml 0.1 *M* HCl used for sample titration

B = ml 0.1 *M* HCl used for blank titration

N = concentration of HCl

14 = atomic weight of nitrogen

W = weight of sample in gram

3.3.3.3 Phosphorus

A 0.5 g of the compost was ashed in a muffle furnace at 500 ^{0}C for 1 hour after which the ash was dissolved in 2.0 *N* HCl solution, heated and filtered. The filtrate was diluted to 100 ml with distilled water.

A 5 ml aliquot of the filtrate was taken into a 25 ml volumetric flask. Following this, few drops of molybdate solution and reducing agent were added and made up to the 25 ml mark with distilled water and allowed to stand for 10 minutes for full colour development. A standard curve was also developed concurrently with phosphorus concentrations ranging from 0, 5, 10, 15 to 20 mg P/kg organic material. The absorbance of the sample and standard solutions were read on a spectronic 21 D spectrophotometer at a wavelength of 520 nm. A standard curve was obtained by plotting the absorbance values of the standard solution against their respective concentrations. Phosphorus concentrations of the samples were determined from the standard curve.

3.3.3.4 Potassium

Potassium in the ash solution was determined using a flame photometer. Standard solutions were prepared with concentrations of 0, 20, 40, 60, 80 and 100 mg/litre of solution. The emission values were read on the flame analyzer. A standard curve was obtained by plotting emission values against their respective concentrations.

3.3.3.5 Magnesium

A 10 ml aliquot of the ash solution was put in an Erlenmeyer flask. The sample was nebulized into an air-acetylene flame, where it was vaporized. Magnesium compounds were atomized and the magnesium atoms thus formed absorbed radiation from a hollow-cathode lamp. The absorbance was measured at wavelength of 285.2 nm. Since the magnesium signal is easily depressed by aluminum, silicon, titanium, and phosphorus, a releasing agent like lanthanum or potassium (0.1% as chloride) was added.

3.4 Soil sampling

Wet soil samples were taken every month (18 samples from July to October) close to the base of five plants selected at random per plot at a depth of 15 cm. The soils were bulked in a bucket, mixed thoroughly and a sub-sample from each treatment plot taken to the laboratory for preparation and analysis.

Moist soil samples were air-dried for one week, followed by crushing and sieving through a 2 mm mesh sieve. However, samples for ammonium and microbial biomass determinations were stored frozen or refrigerated at 4 ^oC and not dried before the analysis. Prior to the establishment of the cropping system, soil samples were also taken from the experimental field, analyzed and used to determine the initial fertility status of the soil.

3.5 Soil analyses

The following soil chemical properties were determined.

3.5.1 Soil pH

The pH of the soil was potentiometrically measured in the supernatant suspension of a 1:2.5 soil: water (w/v) mixture. A 20 g soil sample was weighed into a 100 ml beaker. To this 50 ml distilled water was added and the suspension stirred for 30 minutes. The pH was then measured with a pH meter which was calibrated with buffer solutions at pH 4 and 7.

3.5.2 Soil organic carbon

Organic carbon was determined by the modified Walkley and Black method (Nelson and Sommers, 1982). One gram soil sample was weighed into a flask. A blank sample was also included. Ten milliliters of 1 *N* $K_2Cr_2O_7$ solution was added to the soil and the blank flask. To this, 20 ml of concentrated H_2SO_4 was added. The heat generated by mixing H_2SO_4 and H_2O raises the temperature sufficiently to induce a very substantial oxidation of the organic matter within the first five minutes. Distilled water and 10 ml of concentrated orthophosphoric acid were added and allowed to cool. After 30 minutes, the residual of $K_2Cr_2O_7$ was titrated against 0.5 *N* $FeSO_4$ solution using diphenylamine as indicator.

Calculation:

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

where

m.e. = normality of solution × ml of solution used

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

1.32 = correction factor

3.5.3 Soil total nitrogen

This was determined using colorimetric analysis by the salicylate/nitroprusside method. The determination is based on the Berthelot reaction in which a phenol derivative (salicylate) forms an azo dye in the presence of ammonia and hypochlorite.

A 1.0 g soil sample was weighed into a digestion tube. The larger part of organic matter was oxidized by hydrogen peroxide at relatively low temperature. After decomposition and evaporation of water, the digestion was completed by concentrated sulphuric acid at elevated temperature under the influence of selenium catalyst.

The ammonium reacted with salicylate in the presence of hypochlorite (oxidant) and nitroprusside (catalyst) to form an emerald green colour measured colorimetrically on an auto-analyzer at a wavelength of 660 nm. The reaction takes place in a buffered alkaline medium at a pH of 12.8 - 13.0. The N content was then measured.

3.5.4 Available phosphorus

Available P was determined using the Bray P1 method (Olsen and Sommers, 1982). Phosphorus was extracted by shaking 4.0 g of air dried soil in 28 ml of 0.025 *M* HCl and 0.03 *M* NH_4F mixture for one minute and was determined in the filtrate by the molybdate-blue method using ascorbic acid as a reductant. Colour development was measured at 882 nm on a visible spectrometer. The concentration of P in the extract was obtained by comparing the results with a standard curve.

3.5.5 Exchangeable potassium

Potassium in the soil were determined by flame photometry. A 3 g air dried soil was shake in 30 ml of 1.0 *M* NH_4OAc (pH 7) for 30 min, followed by centrifugation. The sample was nebulized into air-propane flame, where it was vapourized; potassium compounds were atomized and the potassium atoms thus formed emited radiation of which the intensity was measured at a wavelength of 766.5 nm.

3.5.6 Soil mineral nitrogen (NH_4^+-N and NO_3^- -N)

The soil NH_4^+ and NO_3^- were extracted using the colorimetric method of Tel and Heseltine (1990). The mineral forms of nitrogen were extracted by shaking 10 g of moist soil with 25 ml of 1.0 *M* KCl for 30 minutes. The extract was analyzed for ammonium colorimetrically on an Alpkem Rapid Flow Analyzer at 660 nm as described in total nitrogen extraction. Nitrate was determined from the same extract using the Tchnicon Auto-analyzer.

3.5.7 Soil microbial biomass analysis

Soil microbial biomass is an important component of soil quality assessment because of its important roles in nutrient dynamics, decomposition of organic amendments and physical stabilization of aggregates (Franzlubbers *et al.,* 1999). Microbial biomass as determined by the fumigation-extraction method subjects a fresh soil to chloroform fumigation that results in cell wall lyses, allowing the cellular contents to become extractable.

3.5.7.1 Soil microbial carbon and nitrogen

Soil microbial C and N were monitored following the application of both organic and inorganic nutrient sources in the field experiment. Two 10 g field moist soil samples were placed in two different 50 ml beakers and each placed in desiccators. A dish containing 30 ml chloroform was placed at the centre of one of the desiccator. The other desiccator containing the non-fumigated samples served as the control. The desiccators were covered and allowed to stand at room temperature for five days. The soil samples were then transferred into 250 ml shaking bottles and 50 ml K_2SO_4 solution added. The mixture was shaken for 30 minutes. The extract was filtered through Whatman filter paper and the filtrate retained for analysis. An aliquot of 8 ml of the extract was used for organic C determination (Vance *et al.*, 1987). Microbial biomass carbon was calculated from the difference in extractable organic C between the fumigated and non-fumigated soil samples as follows:

Microbial biomass C (mg/kg soil) = [(C fumigated soil) – (C non-fumigated soil)] /K_C

where $K_{C =}$ a coefficient of extraction efficiency (K_C = 0.45)

Total nitrogen in the extracts was measured by the Kjeldahl digestion procedure. Microbial biomass nitrogen was calculated using the equation:

Microbial biomass N (mg/kg soil) = [(N fumigated soil) – (N non-fumigated soil)] /K_N $K_{N =}$ a coefficient of extraction efficiency (K_N = 0.54) (Brookes *et al.*, 1985).

3.5.7.2 Soil microbial phosphorus

Microbial P was determined using the fumigation-sorption method of Morel *et al.* (1996) modified for use with tropical soils by Oberson *et al.* (1997). A 5 g soil sample was fumigated with chloroform. Another soil sample (5g) without chloroform served as control. Following fumigation, samples were extracted with 35 ml of Bray's solution (0.025 *M* HCl + 0.03 *M* NH_4F), filtered and stored for analysis. Solutions were analyzed for P by the ammonium molybdate ascorbic acid method (Olsen and Sommers, 1982). Microbial biomass P estimates were obtained using the relationships described by Morel *et al.* (1996) and as follows:

Microbial biomass P (mg/kg soil) = [(P fumigated soil) – (P non-fumigated soil)] /K_P

$K_{P =}$ a coefficient of extraction efficiency (K_P = 0.4) (Brookes *et al.*, 1982)

3.5.8 Particle size analysis

Particle size analysis was carried out by the settling method which is based on Stokes' Law. This method determines the approximate proportion of sand (2000-50 μm), silt (50-2 μm) and clay (< 2 μm) particles in a soil. Twenty grams of air-dried (crushed to < 2 mm) soil was shaken for 16 hours with 100 ml of 5% sodium hexametaphosphate. The suspension was quantitatively transferred to a sedimentation cylinder and brought to a total volume of 1000 ml with deionized water. A hydrometer was used to measure the density of the suspension of soil and water at 40 seconds and 3 hour whilst a thermometer was used to measure the temperature at each reading.

Calculations :

$$\% \text{ Sand} = 100 - [H_1 - 0.2 (T_1 - 20) - 2.0] \times 2$$

$$\% \text{ Clay} = [H_2 + 0.2\ (T_2 - 20) - 2.0] \times 2$$

$$\% \text{ Silt} = 100 - (\% \text{ Sand} + \% \text{ Clay})$$

where:

H_1 = Hydrometer reading at 40 seconds

H_2 = Hydrometer reading after 3 hours

T_1 = Temperature at 40 seconds

T_2 = Temperature after 3 hour

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

- 2.0 = Salt correction to be added to hydrometer reading.

3.6 Crop harvest and determination of growth and yield parameters

Harvest of millet was done at physiological maturity. The millet grains were air dried, threshed and winnowed. The grain dry weight per plot was then determined and extrapolated to kg ha^{-1}. Stover weight was also determined per treatment plot after oven drying for 48 hours to a constant weight. Harvest index was computed by dividing grain yield by total biomass yield and expressed in percentage.

3.7 Data analysis

All statistical analyses of data were performed in separate analysis of variance (ANOVA) using GenStat package 12 and treatment means separated by the least significance difference (Lsd) method at 5%.

CHAPTER FOUR

4.0 RESULTS

4.1 Physical and chemical properties of the soil at the study site

The soil was initially characterized in order to assess its fertility status before the establishment of the cropping system and application of amendments. The results of the initial physical and chemical analyses are presented in Table 4.1.

Table 4.1. Physico-chemical properties of the soil at the study area

Soil characteristics	Min	Max	Mean	SD	CV (%)
pH (1:2.5 H_2O)	5.19	6.20	5.46	0.29	5.40
Organic C (%)	0.04	0.06	0.05	0.01	16.10
Total N (%)	0.007	0.010	0.01	0.02	23.40
Available P (mg/kg)	4.30	5.40	4.85	0.74	15.40
Exchangeable K ($cmol^+$/kg)	0.06	0.11	0.09	0.02	22.22
NH_4^+ (mg/kg)	0.82	1.22	1.03	0.44	28.40
NO_3^- (mg/kg)	3.58	4.98	4.05	1.87	27.20
Cmic (mg/kg)	6.35	36.85	20.88	1.77	15.30
Nmic (mg/kg)	2.00	36.50	18.98	2.90	8.50
Pmic (mg/kg)	0.003	0.044	0.022	0.001	5.60
Sand (%)	95.07	95.90	95.49	0.60	6.28

Silt (%)	2.00	2.21	2.11	0.61	28.90
Clay (%)	2.40	2.80	2.60	0.20	7.69

Cmic: Microbial biomass carbon; Nmic: Microbial biomass nitrogen; Pmic: Microbial biomass phosphorus; SD: Standard deviation; CV: Coefficient of variation; Values are means of three replications.

The soil pH ranged from 5.19 - 6.20 with a mean value of 5.46. Soil organic carbon and total nitrogen contents varied from 0.04 to 0.06% and 0.007 to 0.010%, respectively. Available phosphorus content varied from 4.30 to 5.40 mg/kg soil. Ammonium -N and nitrate -N contents of the soil ranged between 0.82 and 1.22 mg N/kg soil and 3.58 and 4.98 mg N/kg soil, respectively. Among the microbial properties, biomass phosphorus (Pmic) showed the least variability whilst biomass carbon (Cmic) showed the highest. The pH and Pmic were the least variable soil properties with a CV of $< 6\%$.

4.2 Chemical characteristics of millet glume compost and other organic materials

The results of the chemical analyses of millet glume compost are presented in Table 4.2. The total organic carbon content was 35.34% whilst total N, P, K contents were 0.86%, 0.73% and 0.20%, respectively. The C / N ratio of the MGC was < 45.

Before composting, the millet glumes were also characterized (Table 4.2). Results indicated lower total nutrient composition of the glumes than the compost signifying that composting enhanced nutrient composition of the millet glumes. Total K content of the compost was double the values recorded for the glumes. Whilst the total carbon contents of the glumes and the compost were similar, total P content of the compost was more than five times higher than that of the glumes. The C / N ratio of the two materials were uncomparable as the MGC was of a relatively higher quality than the glumes. On the other hand, the C / N ratio of the catle manure used during compost was 69.71 (Table 4.2)

Table 4.2. Chemical characteristics of millet glume compost

Total nutrients (%)	Organic materials		
	Catle manure	**Millet glumes**	**MGC**
Organic C	55.77	35.51	35.34
Nitrogen	0.80	0.34	0.86
Phosphorus	0.67	0.13	0.73
Potassium	0.11	0.10	0.20
Magnesium	21.56	3.90	31.07
C / N ratio	69.71	104.44	41.09

MGC: Millet glume compost

4.3 Ammonium-nitrogen and nitrate-nitrogen dynamics

The ammonium -N values as observed under the millet glume compost and the mineral fertilizers treatments was < 5 mg/kg soil (Fig 4.1). The highest level of ammonium -N (4.51 mg/kg soil) was recorded at 12 weeks after sowing (WAS) whilst the lowest (0.56 mg/kg soil) was obtained at 4 WAS. At 4 WAS, a net increase in NH_4^+ -N in plots amended with MF and C 150g + MF was obtained whilst a net decrease was recorded in the others over the initial values. Significant differences ($P < 0.05$) were observed between treatment plots at 0, 4 and 12 WAS except at the 8th week. The control plot produced the lowest NH_4^+ -N levels at 4 WAS which differed significantly from the amended plots.

For the three sampling periods, plots treated with compost did not significantly influence ammonium -N. The similarity between plots treated with compost alone and plots treated with its combination with MF means that the addition of mineral fertilizers to compost did not influence ammonium release from the compost.

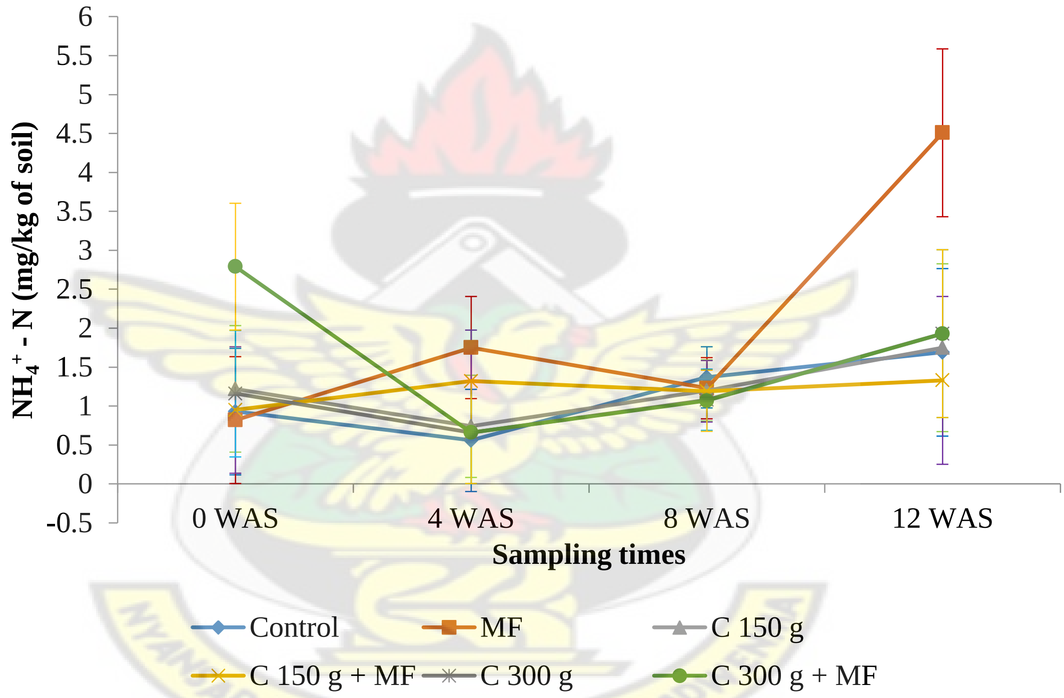

Figure 4.1. Ammonium -N dynamics under millet glumes compost and mineral fertilizers. Bars indicate Lsd (5%)

The nitrate -N under MF treatment showed a slight decline from 0 WAS to 8 WAS and thereafter increased considerably to 22.47 mg/kg at 12 WAS (Fig. 4.2). A similar trend was observabed for all plots except at 4 WAS where C 150 g + MF showed slight increase over values recorded at 0 WAS. The lowest level of nitrate-nitrogen was recorded following 8 WAS. The levels of NO_3^- under the treatments increased remarkly from the 8th week to the 12th week after sowing. Values recorded at the 12th week were 3 - 4 times higher than values observed at the 8th week. Results showed that addition of mineral fertilizers to compost did not influence the release of nitrate from the added organic sources (Fig. 4.2).

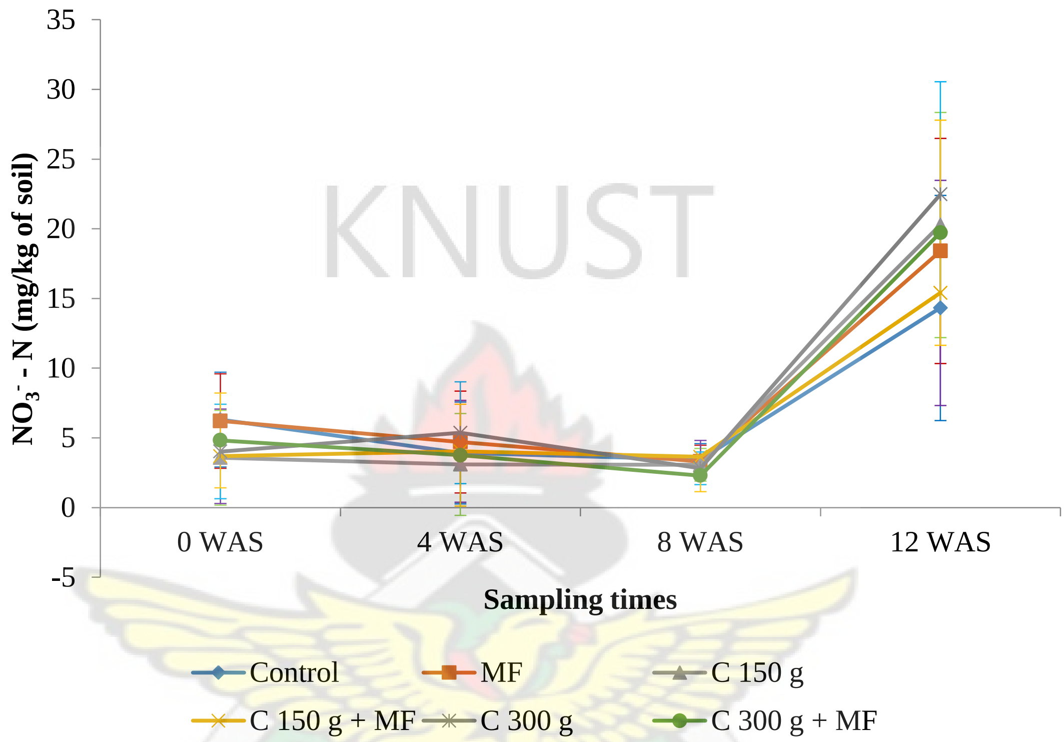

Figure 4.2. Nitrate -N dynamics under the amendments. Bars indicate Lsd (5%)

4.3.1 Ammonium -N to nitrate -N ratio

The ammonium / nitrate ratios as observed under the millet glume compost and the mineral fertilizer ranged from 0.09 to 0.61 (Table 4.3). The highest values were recorded under all amendments at 8 WAS whilst the least values were generally observed at 12 WAS. Values recorded at 8 WAS ranged from 0.39 to 0.61 whilst those recorded at 12 WAS ranged from 0.09 – 0.26. However, NH_4^+ -N / NO_3^- -N values exhibited great variability at all sampling periods except at 8 WAS when the least CV of 32.0% was recorded (Table 4.3). NH_4^+ -N / NO_3^- -N ratios were significantly ($P < 0.05$) affected by the amendments at all periods of sampling. The ammonium / nitrate ratio showed a decrease at 12 WAS due to the high level of nitrate in the soil.

Table 4.3. Ammonium to nitrate ratio as affected by micro - dose application of millet glume compost and mineral fertilizer amendments

	Ammonium -N / Nitrate -N ratio			
Treatment	0 WAS	4 WAS	8 WAS	12 WAS
Control	0.17	0.19	0.46	0.12
MF	0.15	0.48	0.53	0.26
C 150 g	0.44	0.30	0.41	0.09
C 150 g + MF	0.32	0.34	0.39	0.09
C 300 g	0.37	0.14	0.56	0.09
C 300 g + MF	0.55	0.20	0.61	0.10
Lsd (p <0.05)	0.07	0.23	0.11	0.06
CV (%)	65.6	78.5	32.0	88.8

WAS: Week after sowing; Lsd: Least significant difference; NS: Non significant; MF: Mineral fertilizers; C 150 g: 150 g compost; C 300 g: 300 g compost

4.4 Microbial biomass carbon and nitrogen

Microbial biomass carbon and nitrogen showed variations under the amendments during the study period (Fig. 4.3 and 4.4). Generally, biomass values under each amendment at 12 WAS were significantly ($p < 0.05$) higher than their corresponding values at 4 WAS. At 12 WAS, the microbial biomass N under the amendments and the control decreased in the order: C 300 g + MF > C 150 g + MF > C 300 g > MF > C 150 g > control (Fig 4.3). A similar trend was observed at 4 WAS except where the MF treatment recorded lower values than C 150 g. At both sampling periods, higher biomass N was recorded under the amendments than under the control. The biomass N values generally ranged from 6.35 to 51.75 mg/kg soil.

Like biomass N, biomass C was significantly higher ($P < 0.05$) under the C 300 g + MF amendment than all other amended plots and the control (Fig 4.3). Specifically, Cmic values for C 300 g + MF differed significantly from that recorded under sole application of C 300 g. Biomass C values recorded under both treatments were statistically similar ($P > 0.05$) at 12 WAS. The Cmic at 12 WAS was generally higher ($P < 0.05$) than that at 4 WAS.

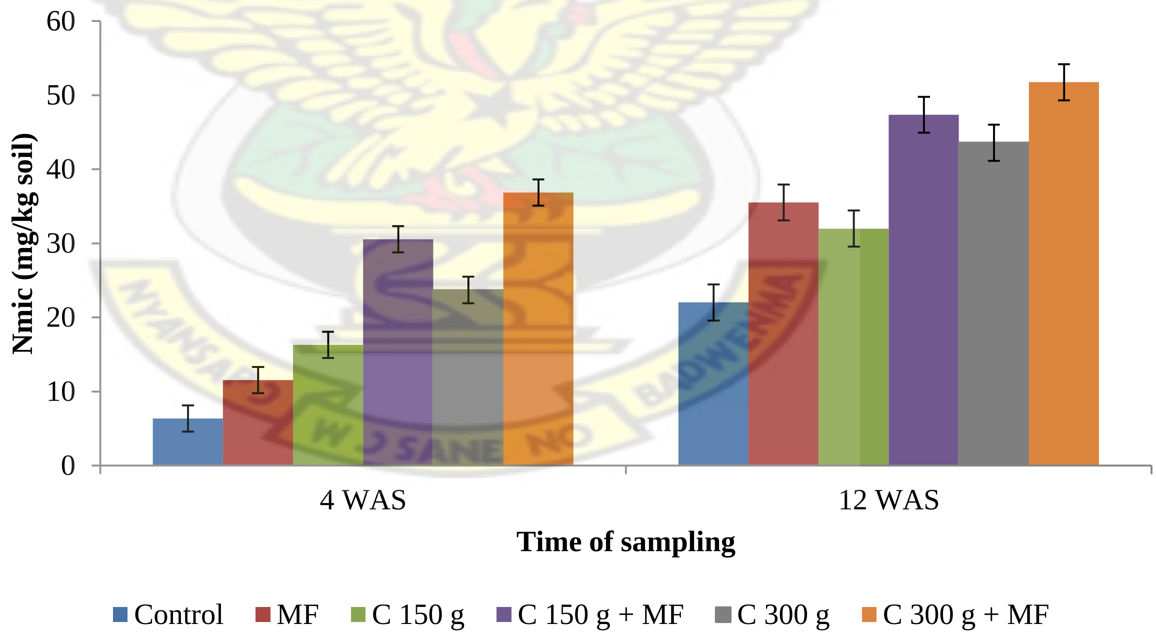

Figure 4.3. Microbial biomass N under micro-dose application of millet glume compost and mineral fertilizers amendment. Bars indicate Lsd (5%)

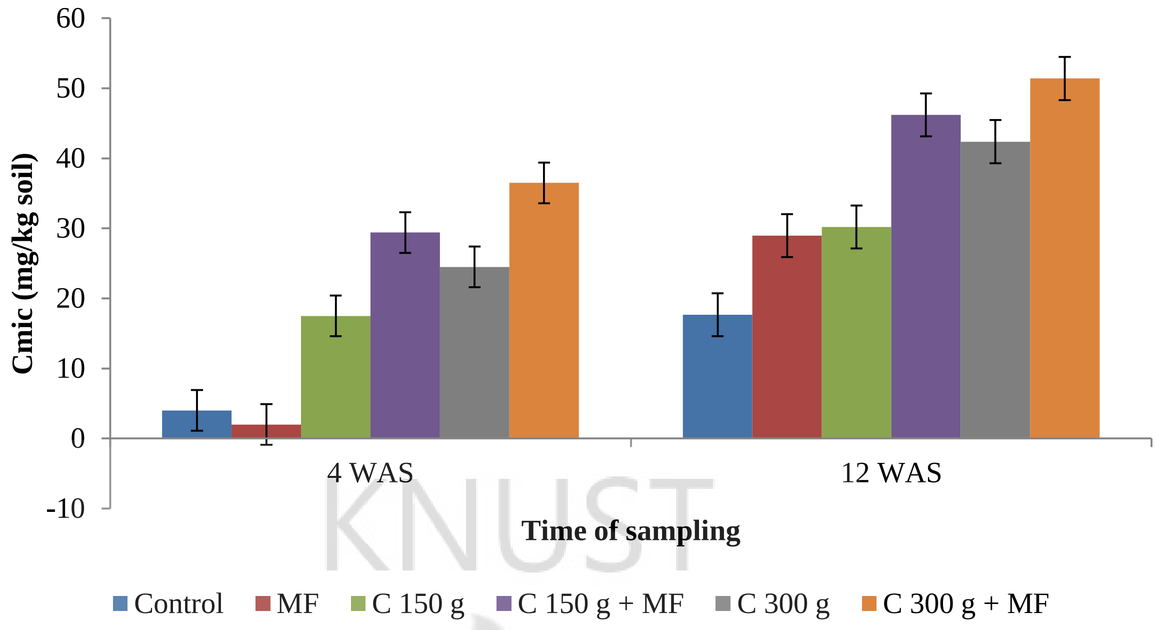

Figure 4.4. Microbial biomass C under millet glume compost and mineral fertilizers application. Bars indicate Lsd (5%)

4.4.1 Microbial biomass carbon to nitrogen ratio

Table 4.4 shows the computed biomass carbon / nitrogen ratios (Cmic / Nmic). There were variations in the Cmic / Nmic ratios at both times of sampling. The results as observed under the millet glumes compost and the mineral fertilizer ranged from 0.17 - 1.07. Generally higher values were recorded at 12 WAS than at 4 WAS. The highest ratio was observed under the C 150 g at 4 WAS whilst the lowest was recorded on the MF amended plots. The Cmic / Nmic ratios showed constancy for C 300 g + MF at both sampling periods suggesting that the Cmic and the Nmic increased proportionally.

Table 4.4. Biomass carbon to biomass nitrogen ratios under micro - dose application of compost and mineral fertilizers amendment

	Cmic / Nmic Ratio	
Treatment	4 WAS	12 WAS
Control	0.63	0.80
MF	0.17	1.02
C 150 g	1.07	0.91
C 150 g + MF	0.96	0.98
C 300 g	1.03	0.97
C 300 g + MF	0.99	0.99
Lsd (p <0.05)	0.27	0.15
CV (%)	18.70	8.70

Cmic: Microbial biomass carbon; Nmic: Microbial biomass nitrogen; WAS: Week after Sowing; Lsd: Least significant difference; CV: Coefficient of variation; MF: Mineral fertilizers; C 150 g: 150 g compost; C 300 g: 300 g compost

4.5 Microbial biomass phosphorus

Application of the different treatments significantly affected the microbial biomass P content of the soil at both periods of sampling (Fig 4.5). The values as observed under the millet glume compost and the mineral fertilizer were < 0.70 mg/kg soil. The microbial biomass P showed an increase towards the end of the study. Almost all treatments with compost recorded higher biomass P except for C 150 g which was less than that of the MF. The Pmic was highest under the C 300g + MF treatment (0.660 mg/kg soil) at 12 WAS. Statistically, there were no significant differences between C 300 g + MF, C 150 g + MF and C 300 g at 12 WAS, and also between MF, C 150 g and the control during the same period. However at 4 WAS, all amendments were significantly different from each other. Microbial P values were generally lower than values reported in literature.

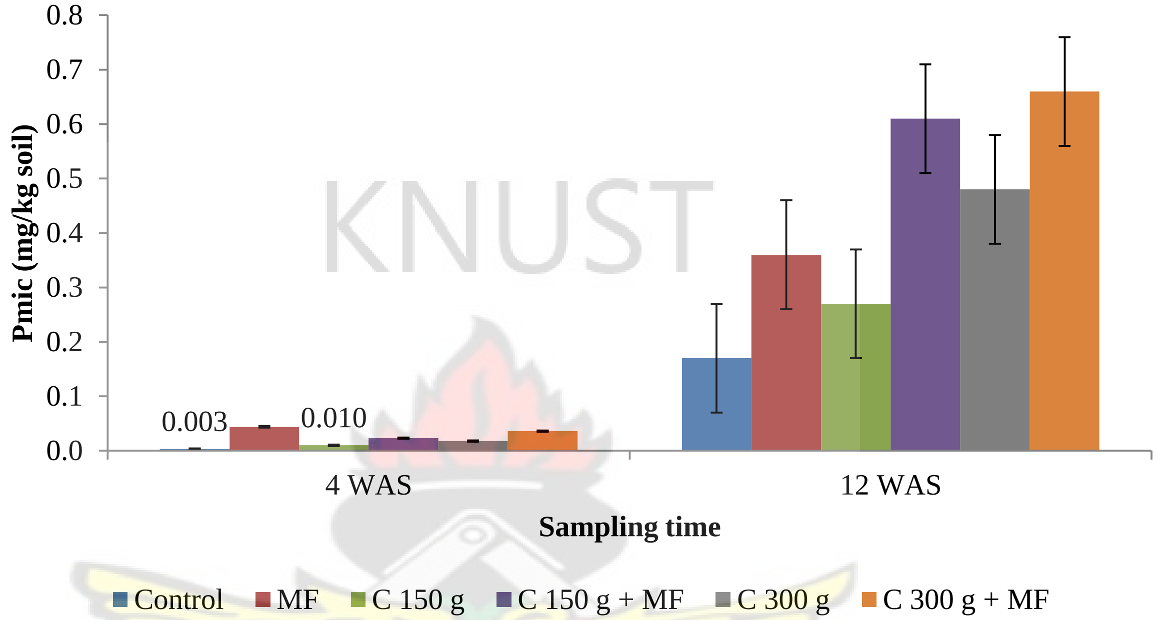

Figure 4.5. Microbial biomass P as affected by the amendments. Bars indicate Lsd (5%)

4.6 Soil organic carbon and total N

Table 4.5 shows soil organic C and total N under the different amendments before (0 WAS) the establishment of cropping system and at harvest (12 WAS). Differences between amendments with respect to organic C and total N at 12 WAS were not significantly different ($p > 0.05$). Before imposition of amendments, organic carbon content of plots marked to receive C 300 g + MF treatment was significantly higher than all other plots. Significant differences ($P < 0.05$) were generally observed between amended plots and the control at 12 WAS for total N content. Unlike organic carbon, the highest total nitrogen level was recorded at 12 WAS for C 300 g + MF plot. Generally, the level of organic carbon and total nitrogen under the amendments were low at the beginning of the cropping season and gradually increased at the end of the study.

Table 4.5. Soil organic C and total N as affected by amendments

	Organic C (%)		Total N (%)	
Treatment	0 WAS	12 WAS	0 WAS	12 WAS
Control	0.04	0.09	0.007	0.009
MF	0.05	0.11	0.010	0.012
C 150 g	0.05	0.10	0.010	0.010
C 150 g + MF	0.04	0.10	0.008	0.011
C 300 g	0.04	0.09	0.009	0.010
C 300 g + MF	0.06	0.10	0.010	0.012
Lsd (p <0.05)	0.01	0.04	0.01	0.04
CV (%)	16.10	23.00	31.10	22.30

WAS: Week after Sowing; Lsd: Least significant difference; CV: Coefficient of variation; MF: Mineral fertilizers; C 150 g: 150 g compost; C 300 g: 300 g compost

4.7 Relationship between some soil chemical properties and microbial biomass

It has been established in literature that microbial biomass plays a significant role in the availability of many nutrients. To verify this assertion, correlation analyses were used to determine the relationship between soil chemical and microbiological properties. Among the chemical properties monitored under the amendments, soil organic carbon, nitrate and total N positively correlated with microbial biomass

(Figs. 4.6, 4.7, 4.8 and 4.9). Microbial biomass carbon showed significant correlation ($P < 0.05$) with soil organic carbon (Fig 4.6). Similar results were observed for the relationship between soil nitrate and Cmic, and between soil nitrate and Nmic (Figs. 4.7 and 4.8). Though a high correlation ($r = 0.75$) was observed between total N and Nmic it was not significant at $p < 0.05$ (Fig 4.9). The microbial biomass increased with increasing concentration or levels of the soil chemical properties (Fig. 4.6 - 4.9).

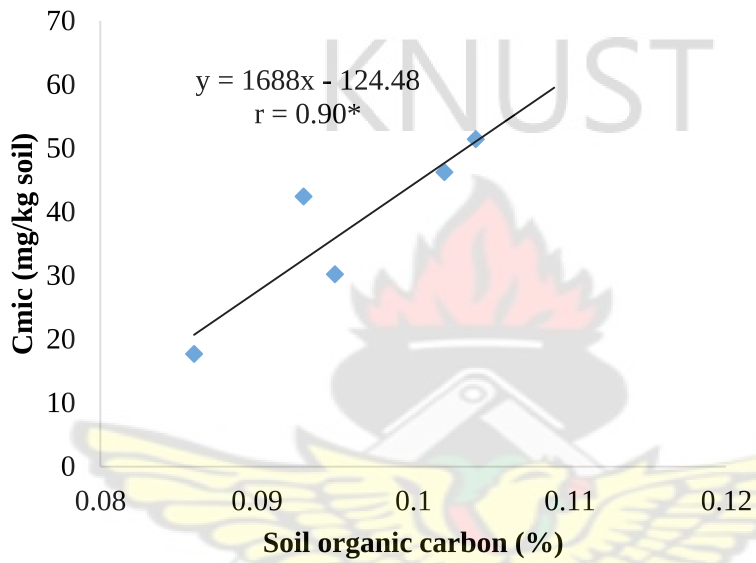

Figure 4.6. Relationship between soil organic carbon and microbial biomass carbon. *Significant at 5%

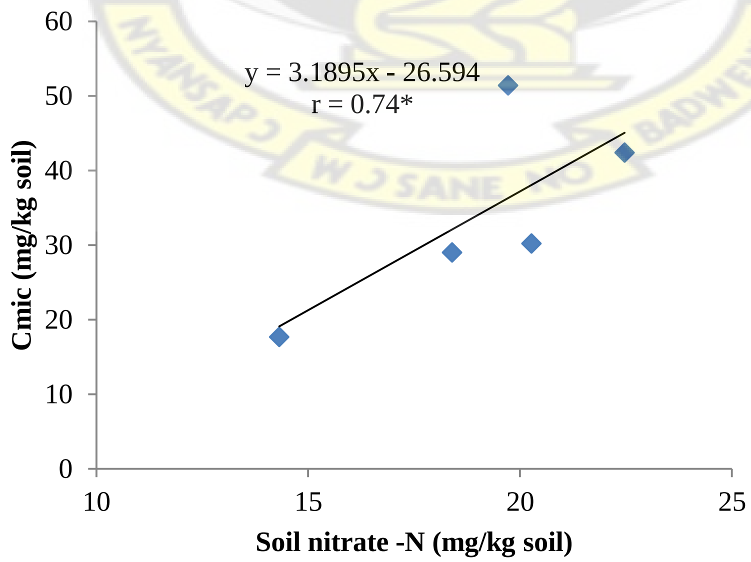

Figure 4.7. Relationship between soil nitrate and microbial biomass carbon. *Significant at 5%

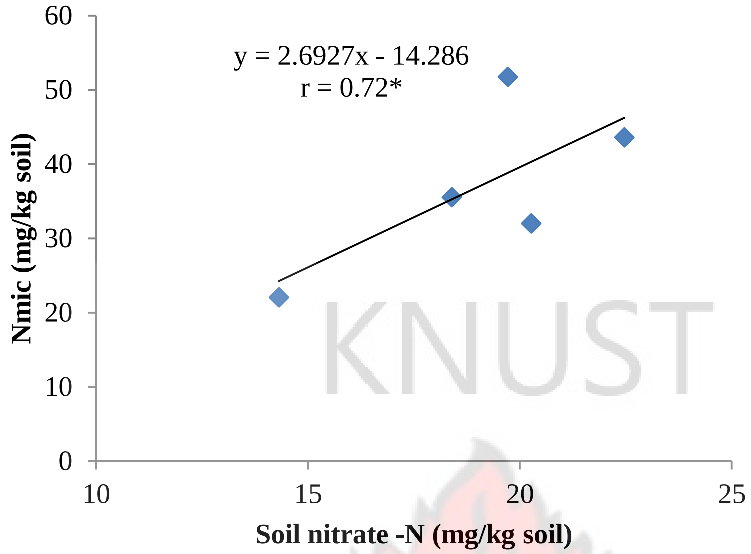

Figure 4.8. Relationship between soil nitrate - N and microbial biomass nitrogen. *Significant at 5%

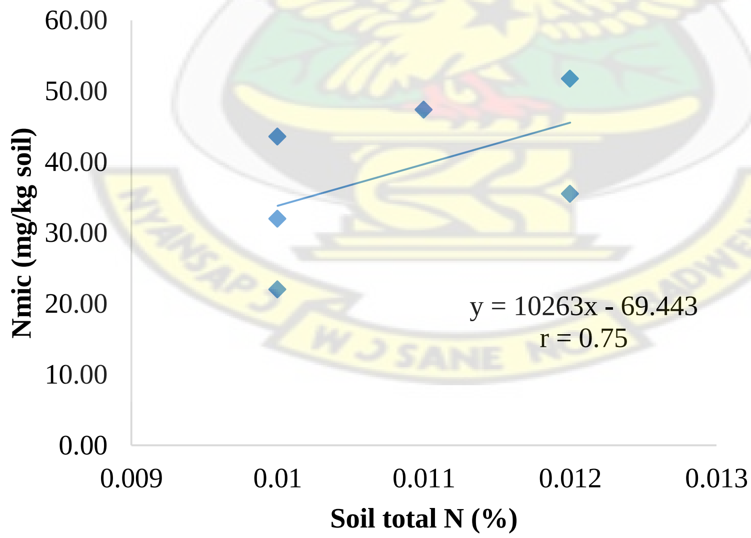

Figure 4.9. Relationship between soil total N and microbial biomass nitrogen

4.8 Relationship between soil mineral nitrogen and total N

Correlation analyses were also used to determine the relationship between soil total N and mineral nitrogen. A low correlation was found between total N and nitrate -N (Fig. 4.10). The regression equations relating soil total N to ammonium -N (Fig 4.11) showed a linear relationship between them. However, the correlation coefficients as observed between NO_3^-, NH_4^+ and total N were not significant ($P > 0.05$) (Figs 4.10 and 4.11).

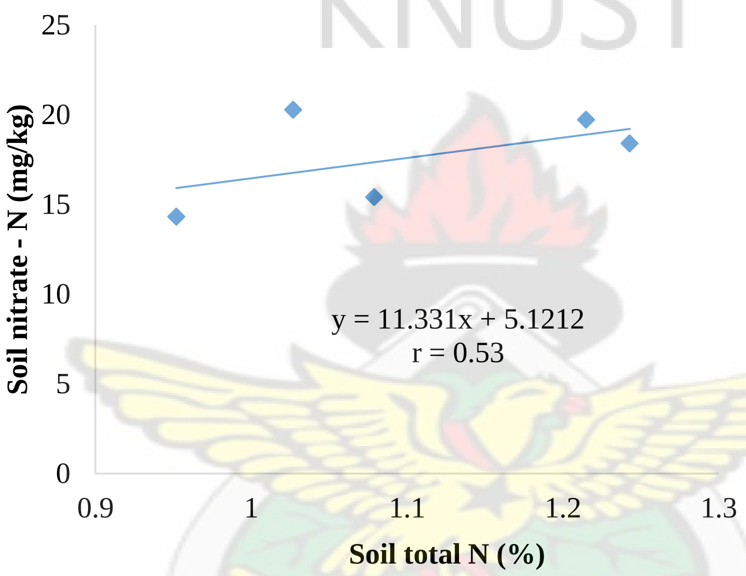

Figure 4.10. Relationship between soil total N and soil nitrate-nitrogen

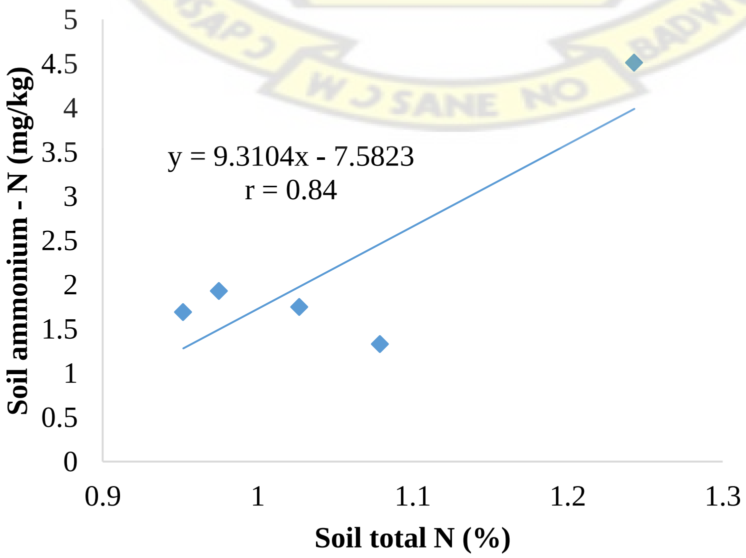

Figure 4.11. Relationship between soil total N and soil ammonium-nitrogen

4.9 Microbial biomass carbon to soil organic carbon ratio

The microbial biomass carbon / soil organic carbon ratios under the millet glumes compost and the mineral fertilizers ranged from 0.40 to 7.35 (Table 4.6). The highest value was recorded under the C 150 g + MF at 4 WAS whilst the lowest was observed for MF treated plots at the same sampling period. There were significant differences ($P < 0.05$) in microbial biomass carbon / soil organic carbon ratios under the different amendments at 4 and 12 WAS.

Table 4.6. Biomass C to soil organic C ratio under compost and mineral fertilizer

	Cmic / Organic C ratio	
Treatment	4 WAS	12 WAS
Control	1.00	1.96
MF	0.40	2.63
C 150 g	3.50	3.02
C 150 g + MF	7.35	4.62
C 300 g	6.13	4.71
C 300 g + MF	6.09	4.80
Lsd ($p < 0.05$)	0.24	1.20
CV (%)	15.70	15.75

Cmic: Microbial biomass carbon; WAS: Week after Sowing; Lsd: Least significant difference; CV: Coefficient of variation; MF: Mineral fertilizers; C 150 g: 150 g compost; C 300 g: 300 g compost

4.10 Microbial biomass nitrogen to soil total N ratio

Higher value was recorded under the C 300g + MF treatment at 4 WAS whilst the lowest was recorded in the control plot (Table 4.7). Generally, amendments influenced the ratios of microbial biomass nitrogen to soil total nitrogen significantly at 4 WAS but not at the 12th week.

Table 4.7. Biomass N to soil total N ratio following compost and mineral fertilizer application

	Nmic / Total N ratio	
Treatment	4 WAS	12 WAS
Control	0.08	0.23
MF	0.10	0.29
C 150 g	0.14	0.31
C 150 g + MF	0.40	0.44
C 300 g	0.26	0.45
C 300 g + MF	0.51	0.43
Lsd ($p < 0.05$)	0.40	0.43
CV (%)	15.95	14.30

Nmic: Microbial biomass nitrogen; WAS: Week after Sowing; Lsd: Least significant difference; Cv: Coefficient of variation; MF: Mineral fertilizers; C 150 g: 150 g compost; C 300 g: 300 g compost

4.11 Millet grain and biomass yields

Results for millet grain and biomass (stover) yields following application of millet glume compost and mineral fertilizer are presented in Figure 4.12 Application of the various amendments significantly ($P < 0.05$) affected millet grain and biomass yields. The plot amended with C 300 g + MF recorded the highest grain yield (1014 kg/ha) whilst the lowest (429 kg/ha) was observed in the control (no amendment). Plots amended with MF, C 150 g and C 300 g + MF produced significantly ($P < 0.05$) higher grain yield than the control. On the other hand, grain yield recorded under C 150 g + MF and C 300 g amendments were statisticaly similar ($P < 0.05$) to that recorded on the control plots. Sole applications of C 150 g and C 300 g produced grain yields which were not significantly different ($P < 0.05$) from each other. However, integrated application of these amendments with mineral fertilizers recorded grain yield values which were significantly ($P < 0.05$) different from each other.

The biomass yield showed similar results as grain yield. It was observed that C 300 g + MF, MF and C 150 g amendments produced more stover yield (1519, 1089 and 1011 kg/ha, respectively) than other plots. Plots amended with C 150 g and C 300 g produced similar stover yield which suggests that the use of C 150 g is more beneficial than C 300 g if applied alone. However, in combination with mineral fertilizers, the C 300 g is the best. Generally, all the amendments produced higher stover yields than the control.

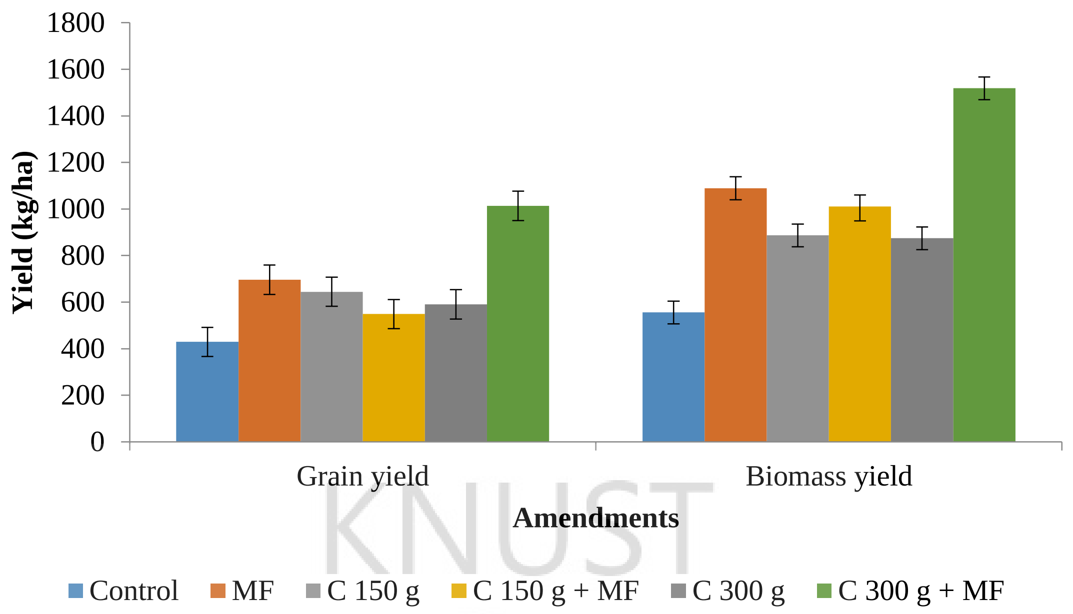

Figure 4.12. Millet grain and biomass yield as affected by inorganic and organic amendments. Bars indicate Lsd (5%)

4.12 Relationship between some soil chemical properties and millet grain yield

Among the soil chemical properties monitored under the amendments, soil organic carbon, ammonium and nitrate positively correlated with millet grain yield (Figs. 4.13; 4.14 and 4.15) with r values of 0.76, 0.69 and 0.64, respectively. The parameters however, showed no significant correlation with millet grain yield.

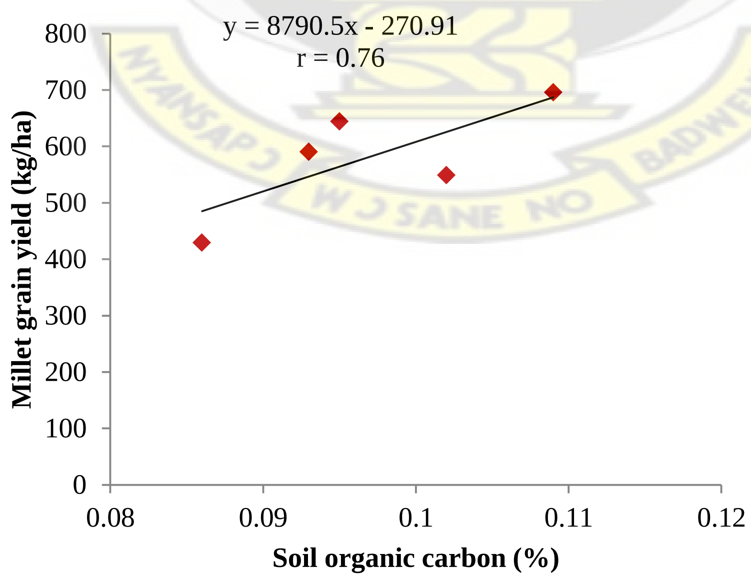

Figure 4.13. Relationship between soil organic carbon and millet grain yield

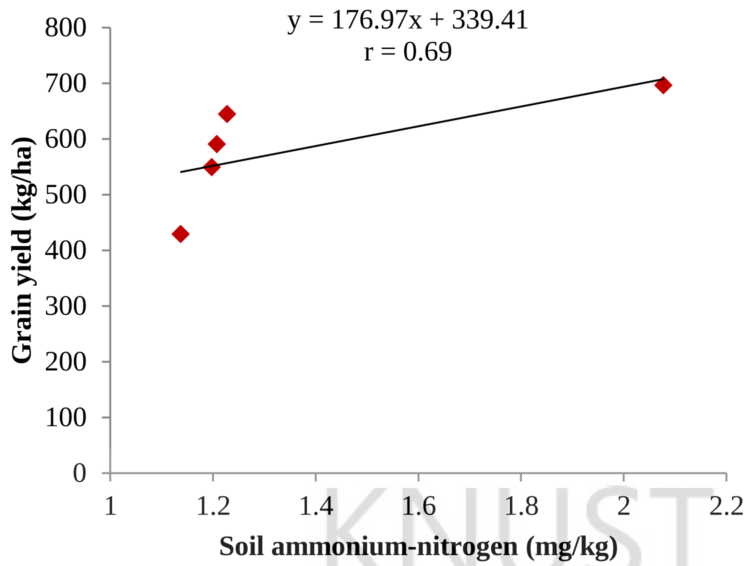

Figure 4.14. Relationship between soil ammonium and millet grain yield

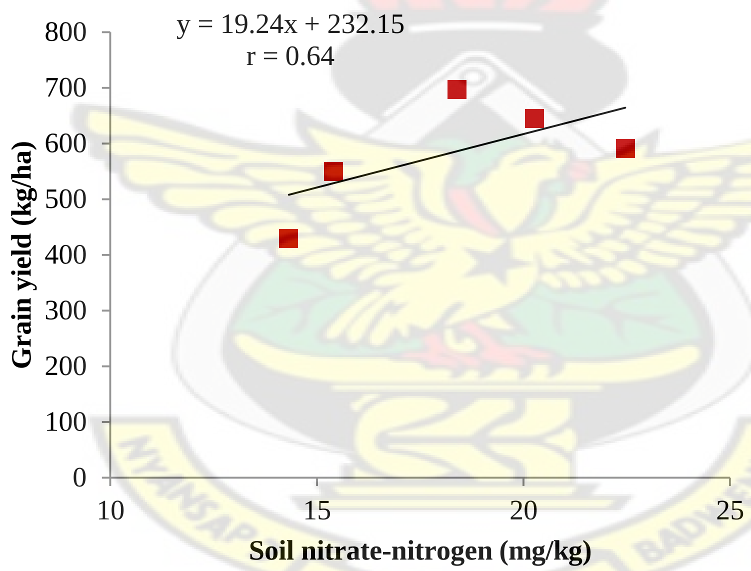

Figure 4.15. Relationship between soil nitrate and millet grain yield.

4.13 Harvest index as affected by amendments

It is the ratio of total economic yield to the total plant dry matter or biomass produced at harvest. The results of harvest index (HI) are shown in Fig. 4.16. Amendments significantly influenced HI. Harvest index was higher in C 150 g, C 300 g and the control (42.70, 42.67 and 42.25%, respectively) than in the other treatments. The least value was recorded for C 150 g + MF which was statistically not different (P > 0.05) from plots amended with MF.

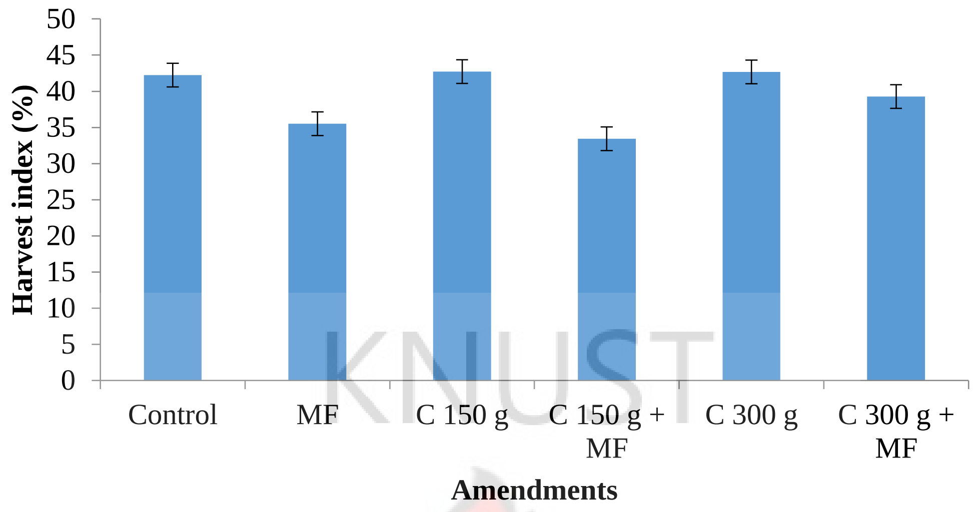

Figure 4.16. Harvest index as affected by the amendments

CHAPTER FIVE

5.0 DISCUSSION

5.1 Physical and chemical properties of the soil at the study site

Initial analysis of the soil at the experimental site (N'Dounga) indicated low organic carbon content and generally low fertility status (Table 4.1). The low soil organic carbon content was the result of high soil temperatures resulting in rapid decomposition of organic matter in combination with a generally low input of organic materials. Carbon plays an important role in sandy soils with low activity clay because it acts as substitute for clay CEC build up and a mediator of nutrient supply in cropping system with low chemical fertilizer input (Asadu *et al.*, 1997). The acidic pH (Landon, 1996) observed was possibly due to leaching of basic cations out of the top soil. This partly accounted for the low available P content of the soil since P is fixed at low (acidic) soil pH by low activity clays.

5.2 Chemical characteristics of millet glume compost

Compost quality is largely determined by its organic constituents and nutrient contents (Bationo, 2008). According to Bationo (2008), compost quality can be assessed from its agronomic characteristics. Agronomically, it is related to its nutrient content (N, P, and K) and organic matter composition (Waas, 1996; Bationo, 2008) which give it a fertilizer value and soil amending power. The N concentration of the MGC was higher (Table 4.2) than the FAO standard (0.4 - 0.5%). Palm *et al.* (2001) also gave a range of N content as 0.4 to 0.8%. The P concentration was within the FAO standard (0.1 - 1.6%) whilst the K content was lower than the FAO range (0.4 – 2.3%). Blair and Boland (1978) found that 0.25% of P is the critical value below which net P immobilization would be expected.

The C / N ratio is a characteristic feature of organic substrates. The C / N ratio of the millet glume compost recorded in this study was 41.10 (Table 4.2) which is higher than the standard value for quality compost. According to Bationo (2008), the C / N ratio of the final product should be between 10:1 and 15:1. Materials with C / N ratio greater than 25 have been reported to lead initially to immobilization whereas those with C / N ratio less than 25 release N (Burgess *et al.*, 2002). Contrary to this expectation, sole application of compost or in combination with mineral fertilizers did not generally lead to immobilization of nitrate and ammonium during the study period.

5.3 Ammonium-nitrogen and nitrate-nitrogen dynamics

Ammonium -N under the amendments showed changes in its level in the soil over time (Fig 4.1). This could be due to microbiological activity and the influence of crop uptake at different stages of growth. This observation is in contrast with that of Snapp and Borden (2005) who reported constant pool size of NH_4^+ -N.

The highest NO_3^- -N recorded under amendments at 12 week after sowing was possibly due to the highest microbial biomass recorded (Figs 4.4, 4.5 and 4.6) at the week 12. The higher microbial biomass values is an indication of microbial activity which resulted in more mineralization of N to produce NO_3^- -N. NO_3^- -N showed remarkable increase from 8 to 12 WAS. On the other hand, the observation could be due to 'Birch effect'. According to Birch (1964) and Appel (1997), there is offen a marked seasonality of organic matter decomposition in the wet and dry tropics due to a flush of decomposition associated with the rewetting of dry soils. This can lead to a pronounced flush of nitrate in the soil at the onset of the rains which is susceptible to leaching in cultivated soils (Birch, 1964). The soil of the study area experienced short dry spell which were followed by resumption of rains (Appendix 2). In Ghana, Nye and Stephens (1962) and Logah (2010) observed gradual increase in soil nitrate levels during the dry season. Birch (1958) indicated that this pattern is repetitive with successive drying and rewetting and is common to all soils. The operation and repetition of this pattern of decomposition in the field has important consequences in the rundown of soil carbon and the mineralization of soil nitrogen (Birch, 1964). The decomposition involves direct microbial attack of the organic substrate and the recurrent pattern of decomposition is due to the state in which the microbial population is left after drying and its subsequent behavior on rewetting (Birch, 1958).

Comparatively NO_3^- -N levels were higher than NH_4^+ -N levels under the amendments (Fig 4.2). This has implication on nitrogen availability in the soil system since nitrogen in the form of NO_3^- is more subject to leaching or denitrification losses. According to Tsai *et al.* (1992) nitrogen maintained as NH_4^+ in the soil should be available for late season uptake. The results of the study indicated no immobilization of NO_3^- at all periods of sampling. In some agricultural soils, no NO_3^- immobilization has been observed (Shai and Norton, 2000); while in others NO_3^- immobilization was recorded after 1 – 4 weeks (Schimel, 1986) or several months (Kissel and Smith, 1978).

5.3.1 Ammonium -N to nitrate -N ratio

Plants can absorb both ammonium and nitrate as a nitrogen source and therefore, the total uptake of nitrogen usually consists of a combination of these two forms (Bruck and Guo, 2006; Ciampitti and Vyn, 2012). However, research has indicated that the effect of these two forms on plant growth and chemical content is dependent not only on the plant species, but also on the NH_4^+ / NO_3^- ratio and concentrations (Guo *et al.*

2002). In this study, NH_4^+ / NO_3^- ratio under amendments ranged from 0.09 – 0.61 (Table 4.3) with the lowest ratios generally observed at 12 WAS. These low ratios were due to the high levels of NO_3^- recorded at 12 WAS. In his study, Logah (2010) made a similar observation and attributed the high levels of NO_3^- to the occurrence of Birch effect.

The ratios between ammonium and nitrate is of great significance and affects both plants and soil medium (Mills and Jones, 1996). According to Marschner (1995), ammonium / nitrate ratios may change the pH near the roots. These pH changes may affect solubility and availability of other nutrients (Marschner, 1995).

5.4 Microbial biomass carbon and nitrogen

Higher level of microbial biomass C was recorded in plots treated with compost + mineral fertilizers (Fig 4.3). With the addition of compost, more organic matter was added to the soil which facilitated rapid microbial population growth. According to Schnurer *et al.* (1985), the decomposition rate of organic input is responsible for the variation in the level of microbial biomass. Although the quantity of microbial biomass is mainly related to C inputs, other mitigating factors such as temperature and moisture can regulate the growth and activity of the native microflora (Schnurer *et al.,* 1985). In their study, Ajay and Mathieu (2012) reported that compost application increased microbial biomass and had a positive impact on soil microbial functional diversity. Soil organic matter content, total N content and soil microbial population increased with increasing rate of compost application (Chang *et al.*, 2007; Sodhi *et al.*, 2009). Wander *et al*. (1995) and Shannon *et al*. (2002) observed significantly higher microbial biomass C in soils under organic amendment compared to conventional management.

The highest microbial biomass N value was recorded in compost + mineral fertilizers treated plots (Fig 4.4). The application of mineral fertilizers alone resulted in lower microbial biomass N compared to the composted plots. Fliebach and Mäder (2000) reported that increase in the quantity of organic inputs often result in high microbial biomass. Organic farming systems with compost applications had 34% higher microbial biomass than treatments which did involve any manure application (Fliebach *et al*., 2007).

5.4.1 Microbial biomass carbon to nitrogen ratios

The ratio of Cmic / Nmic is often used to describe the structure and state of the microbial community. According to Campbell *et al.* (1991), high Cmic / Nmic ratio indicates that the microbial biomass contains a higher proportion of fungi, whereas a low value suggests that bacteria predominate in the microbial population. The ratios observed at 4 WAS and 12 WAS generally ranged from 0.17 – 1.07 (Table 4.4) which were lower than values recorded in forest and arable lands. Logah (2010) reported mean ratios of 8.1, 14.2 and 35.1 in 2006 major, 2006 minor and 2007 major seasons respectively, in the semi-deciduous forest zone of Ghana.

Joergensen (1995) reported C / N ratios of the microbial biomass varying from 5.2 in an arable land to 20.8 in a forest soil with an average of 6.8 for 82 soils. The values from this study were lower than values reported by Joergensen (1995) and Logah (2010) due to the general poor fertility status (low organic C content) characteristic of Semi-arid Niger compounded by low soil moisture content as a result of eratic rainfall pattern. The Cmic / Nmic ratio is affected by soil properties such as moisture content, pH and substrate availability (Moore *et al.*, 2000). Differences in these ratios are therefore expected between microbial populations cultivated under natural conditions (Joergensen, 1995).

5.5 Microbial biomass phosphorus

Microbial biomass phosphorus was higher in plots treated with compost + mineral fertilizers compared with the sole application of compost, mineral fertilizers and the control plots. Generally no immobilization of P was recorded in microbial cells. Biomass P values recorded in this study were very low compared to values recorded in literature. For example, Logah (2010) observed a range of 5 – 50 mg/kg soil and 30 – 40 mg/kg soil respectively during the major seasons of 2006 and 2007 whilst observing negative values in 2006 minor cropping season. The extremely low values observed in this study could be due to the low available P content of the soil (Table 4.1) since soil microbes have high affinity for phosphorus which can lead to immobilization (Logah *et al.,* 2010 ; 2013).

5.6 Soil organic carbon and total N

The abundance of organic C in the soil and its role as a key control of soil fertility in crop production has been recognized for more than a century (Tiessen *et al.,* 1994). Organic C storage is controlled by the balance of C inputs from plant production and outputs through decomposition (Schlesinger, 1977). In sandier soils, the relative contribution of the organic fraction is high because there is less clay (Wayne *et al.,* 2014). By providing a food source for micro-organisms, organic carbon can help improve soil stability by micro-organisms binding soil particles together into aggregates or 'peds' (Wayne *et al.,* 2014). This study indicated a general increase in organic carbon contents in plots under amendment at 12 WAS over the initial values (0 WAS) (Table 4.5). However, the final organic carbon content of the soil was still low (< 2%) (Landon, 1996). Large organic additions can temporarily increase the organic fraction in a soil, but unless additions are maintained, the soil will revert to its steady state equilibrium, which is usually low (Wayne *et al.* 2014).

Soil total nitrogen levels of 0.007 – 0.012% under amendments and cropping systems were very low (< 0.1%) (Landon, 1996). This was particularly due to the low soil organic carbon levels found in this study following amendment (Table 4.5). According to Logah (2010) the observation could also be partially ascribed to N losses which occur mainly through leaching, volatilization, etc.

5.7 Relationship between some soil chemical properties and microbial biomass

Positive correlation was found between Cmic and soil organic carbon (Fig 4.6). This observation is in conformity with the findings of Beck *et al.* (1997) and Leiros *et al.* (2000) who reported strong correlation between biomass C and organic carbon. However, Insam and Domsch (1989) and Zak *et al*. (1994) found no correlation between the biomass C and organic C. Published data on the relation of microbial biomass C to organic carbon are inconsistent, showing either a positive correlation or no correlation as both the organic carbon quality and the microbial community structure are associated with soil type (Jozef, 2004). The positive correlation obtained in this study could be explained by the fact that microbial biomass concentration depended on organic matter availability to microbial activity as suggested by Insam and Domsch (1989) and Anderson and Domsch (1989).

5.8 Relationship between soil mineral nitrogen and total N

The natural N supply for plants and microorganisms results principally from the mineralization of organic compounds (Runge, 1983). The regression equations relating soil total N to ammonium -N (Fig 4.11) showed a positive correlation (r =

0.84) indicating that substrate availability plays a key role in N mineralization. A linear relationship between nitrate -N and total N was found with r = 0.53 (Fig. 4.10).

5.9 Microbial biomass carbon to soil organic carbon ratio

The Cmic / organic C ratio represents the contribution of microbial biomass to organic carbon in soil (Table 4.6). Insam *et al.* (1989) reported that the clay content of soil has an important influence on the variation in Cmic / soil organic C. Anderson and Domsch (1989) stated that the ratio of soil biomass C to organic C ratio is a good indicator of changes in microbial performance caused by environmental conditions. Though Anderson and Domsch (1989) did not give any indication on soil biomass C / organic C ratio range, the values recorded in this study were lower (Table 4.6) than those repported by FAO (1976) which ranged between 11.4 and 12.8. The observation is attributable to the generally low microbial biomass C content of the soil (Fig. 4.4) by virtue of the low soil organic carbon level recorded (Table 4.5). The structure and distribution of C in soil affect biological activity and probably the microbial biomass (Hatice and Nur, 1998).

5.10 Microbial biomass nitrogen to soil total N ratio

Biomass N values expressed as percentages of soil total N give an estimation of the quantities of nutrient in the microbial biomass and substrate availability (Sparling *et al*., 1990). Moore *et al.* (2000) reported that biomass N made up to 2.4% of soil total N under cropping systems. Logah (2010) indicated that the microbial biomass, served as a repository of soil total nitrogen under amendments. The ratios of Nmic / total N can range from 1 – 7% (Joergensen, 1995). Generally, lower values were recorded under amendments in this study (Table 4.7) indicating that microbial biomass may not necessary serve as a subtantial repository of the soil total N under these field conditions.

5.11 Millet grain and biomass yield

The different amendments influenced millet grain and biomass yields in this study (Fig 4.12). Millet yields obtained under all the amendments were significantly higher than that of the control. Addam *et al*. (2010) reported an increase in millet yields with application of mineral fertilizers, compost or both compared to the non-application. The relatively low yields recorded by the sole application of compost could be attributed to the slow release of nutrients for crop uptake. Only a fraction of the nutrients in compost become plant available in the first year after application (Motavalli *et al.*, 1989; Ramamurthy and Shivashankar, 1996; Eghball, 2002). Eghball and Power (1999) found that 20% of compost N became plant available in the first year after application, indicating that about 80% of compost N became plant available in the succeeding years, assuming little or no loss of N due to NO_3^- -N leaching or denitrification. The combined application of compost and mineral fertilizers recorded the highest yields (Fig 4.12). This was due to the positive effect of integrated nutrient management on the yield of millet. Many workers have demonstrated identical results with combined use of organic and inorganic sources of nutrients (Fatondji *et al.*, 2006).

The results of this study have shown that combination of millet glume compost and inorganic fertilizers could help save 50% dose of fertilizers (like in this study 15 kg/ha of urea instead of the recommended rate 30 kg/ha as reported by Batiano and Ntare, 2000). However, the low grain yield observed was partly due to erratic rainfall received during the study period.

5.12 Relationship between some soil chemical properties and millet yield

The relation between soil organic carbon and millet yield was positive with coefficient of correlation of 0.76 (Fig 4.13). This suggested that soil organic carbon under the various amendments influenced crop yield as expected. Although it has been difficult to quantify the effects of SOC on crop and ecosystem productivity (Dudal and Deckers, 1993) results from experiments in some African countries indicated favourable responses due to SOC (Bationo *et al.*, 2006). Soil organic matter is not only a major regulator of various processes underlying the supply of nutrients and the creation of a favourable environment for plant growth but also regulates various processes governing the creation of soil-based environmental services (Vanlauwe, 2004). According to Swift and Woomer (1993), high SOC status in homestead fields is observed to relate positively with crop yields. Several scientists have attributed the effect of organic amendments on crop yield as partly due to effects of SOC (Powell, 1986; De Ridder and van Keulen, 1990; Bationo and Mokwunye, 1991b; Bationo *et al.*, 1995, 1998). Research results from long-term field experiments in the West African agro-ecosystems showed that the use of mineral fertilizers without recycling of organic materials resulted in higher yields, but the increase was not sustainable (Bationo *et al.*, 2004). As a result of the higher organic carbon content in mulched plots, Bationo *et al.* (1993) reported a large positive and additive effect of crop residue and mineral fertilizer application on pearl millet yield (Bationo *et al.*, 2006)

5.13 Harvest index as influenced by amendments

There was significant influence of compost and mineral fertilizers applied on HI during the cropping season, but all treatments recorded low harvest indices (Fig 4.16). Harvest index of cereal crops has been reported to be within the range of 50 –

60% (Evans, 1993). Low grain crop HI could be attributed to late sowing, imperfect sowing methods, low plant population, poor plant protection, and non-availability of water for irrigation at critical crop growth stages (Ahmad *et al.,* 2007). Non-availability of irrigation at critical growth stage significantly reduces crop HI (Ahmad *et al.,* 2007). The low HI recorded in this study could be attributed to the drought or water stress period experienced critical during crop growth stage. Harvest index is the proportion of plant biomass allocated into grains and is the only known measure of the efficiency of the process and source-sink balance (Lawlor, 2002 and Reynolds *et al.,* 2007).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

The results of the study indicated variations in mineral nitrogen levels at the different periods of sampling. Ammonium -N values (< 5 mg/kg soil) were generally lower than nitrate -N values (< 25 mg/kg soil) under application of millet glume compost and mineral fertilizers and their combinations. This has implication for more losses of N from the soil system since ammonium is less leached compared to nitrate. Since the maintenance of soil nutrient status is an important aspect of sustainability, management of compost and fertilizers to maintain soil fertility is necessary.

Compost application especially in combination with mineral fertilizers (C 300 g + MF) had greater impact on soil microbial biomass C, N and P. With the addition of compost, more organic matter was added to the soil which facilitated rapid microbial population growth. However, the microbial biomass P values (< 0.70 mg/kg soil) recorded in this study were generally low compared to values reported in literature.

The organic carbon and total nitrogen contents under the amendments were low at the beginning and gradually increased at the end of the study. However, the final organic C and total N (0.11 and 0.012%, respectively) content of the soil were still low.

This study has shown the importance and benefit of combined use of millet glume compost and mineral fertilizer nutrient sources in sustaining soil health and crop productivity. Complementary application of 300 g millet glume compost and mineral fertilizers led to higher millet grain yield (1014 kg/ha) than sole applications of each nutrient source.

The study has indicated that micro-dose rate of 300 g compost + 88 g urea + 500 g SSP (3t compost /ha + 15 kg N /ha + 13 kg P /ha) is potentially ideal for crop growth and soil fertility improvement in Semi-arid Niger. Micro-dosing of millet glume compost and application of mineral fertilizers in an integrated nutrient management strategy promised to be an option that famers could adopt to ensure higher yields. Whilst the return of crop residues is being advocated in Niger, improvements in soil fertility would require balanced organic matter and inorganic fertilizer applications. However, the short-term nature of the study is not enough to state a recommendation rate for farmers' use.

6.2 RECOMMENDATION

Use of composted millet glume has a great potential for soil fertility and crop yield improvement. Since the millet straw is always not available (due to its competitive use) and farmers cannot afford mineral fertilizers, they could use millet glume compost for sustainable crop production. However, more research should be conducted on the millet glume compost to assess its long-term effect on the physico-chemical properties of the soil and crop yield and also to calibrate its recommended rate on micro-dosing mode of application.

To promote good composting practices, there is a need to develop a guide on how smallholder farmers can create ideal compost which could be at moderate cost to improve the profitability of composting. There is also the need for further research on complementary application of millet glume compost and inorganic fertilizers under monocropping and intercropping systems in Semi-arid Niger.

REFERENCES

Addam, K. S., Hide, O. and Satoshi, T. (2010). 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.

Adediran, J. A. and Banjoko, V. A. (1995). Response of maize to N, P, and K fertilizers in the savanna zone of Nigeria. Commun. Soil Sci. Plant Anal. 26: 593 - 606.

Adiel, R.K. (2004). Assessment of on-farm adoption potential of nutrient management strategies in Chuka Division, Meru South District, Kenya. Msc Thesis, Kenyatta University, Nairobi.

Ahmad, N., Mohammad, R. and Ulas, K. (2007). Evaluation of different varieties, seed rates and row spacing of groundnut, planted under agro-ecological conditions of Malakand Division. Journal of Interacademia 9(4): 178-183.

Ajay, N. and Mathieu, N. (2012). Soil microbial biomass, functional microbial diversity, and nematode community structure as affected by cover crops and compost in an organic vegetable production system. Applied Soil Ecology 58: 45– 55.

Amlinger, F., Götz, B., Dreher, P., Geszti, J. and Weissteiner, C. (2003) Nitrogen in biowaste and yard waste compost: dynamics of mobilisation and availability – a review. European Journal of Soil Biology 39: 107-116.

Anderson, T. M. and Domsch, K. H. (1989). Ratios of microbial biomass carbon to total organic carbon in arable soils. Soil Biology and Biochemistry 25: 393-395.

Annabi, M., Houot, S., Francou, C., Poitrenaud, M. and Bissonnais, Y.L. (2007). Soil aggregate stability improvement with urban composts of different maturities. Soil Sci. Soc. Amer. J. 71: 413-423.

Appel, T. (1997). Non-biomass soil organic nitrogen: The substrate for nitrogen mineralization flushes following soil drying- rewetting and for organic nitrogen rendered calcium chloride-extraction upon soil drying. Soil Biol. Biochem. 30: 1445-1456.

Ariharia, J. (2000). Cropping systems and the mechanisms of nutrient uptake. National Agricultural Research Centre, Kannondai, Tsukuba, Japan, pp. 1-20.

Arslan, E., Erdal, Ö., Sevda, K., Ubeyde, İ. and Murat, T. (2008). Determination of the Effect of Compost on Soil Microorganisms. International Journal of Science & Technology 3(2): 151- 159.

Asadu, C.L.A, Diels, I. and Vanlauwe, B. (1997). A comparison of the contributions of clay, silt, and organic matter to the effective CEC of soils in sub-Saharan Africa. Soil Science 162: 785-794.

Badiane, O. and Delgado, C. L. (1995). A 2020 vision for food, agriculture and the environment, Discussion Paper 4. International Food Policy Research Institute, Washington, DC.

Barbarick, K. A. (2014). Nitrogen sources and transformations. Colorado State University, U.S. Department of Agriculture and Colorado counties cooperating.

Batiano, A. and Ntare, B.R. (2000). Rotation and nitrogen fertilizer effects on pearl millet, cowpea and groundnut yield and chemical properties in a sandy soil in the semi-arid tropics, West Africa. J.Agric. Res. 134: 277 - 284.

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. In: Williams, T. O., Tarawali, S. A., Hiernaux, P. and Fernandez-Rivera, S. (eds.) Sustainable crop-livestock production for improved livelihoods and natural resource management in West Africa. Proceedings of an international conference. IITA Ibadan, Nigeria, 19-22 November 2001. P. 173-198

Bationo, A. and Buerkert, A. (2001). Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. Nutrient Cycling in Agroecosystems 61: 131–142.

Bationo, A. and Mokwunye, A. U. (1991b). 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. Nutrient Cycling in Agroecosystems 29: 117-125.

Bationo, A. and Mokwunye, A. U. (1992). Role of manures and crop residue in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Soudanian zones of West Africa. Fertilizer Research 29: 217 – 225.

Bationo, A. and Mokwunye, A.U. (1991a). Alleviating soil fertility constraints to increased crop production in West Africa: The experience in the Sahel. Fertilizer Research 29: 95–115.

Bationo, A., Buerkert, A., Sedogo, M.P., Christianson, B.C. and Mokwunye, A.U. (1995). A critical review of crop residue use as soil amendment in the West African semi-arid tropics. In Powell, J.M., Fernandez Rivera, S., Williams, T.O. and Renard C. Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa, edited by Proceedings International Conference, ILCA, Addis Abeba, Ethiopia, pp 305–322.

Bationo, A., Christianson, C. B. and Klaij, M. C. (1993). The effect of crop residue and fertilizer use on pearl millet yields in Niger. Fertilizer Research 34: 252 – 258.

Bationo, A., Job, K., Bernard, V., Boaz, W. and Joseph, K. (2006). Soil organic carbon dynamics, functions and management in West African agro-ecosystems. Agricultural Systems, 13 p.

Bationo, A., Lompo, F.and Koala, S. (1998). Research on nutrient flows and balances in West Africa: State of the art. Agricultural, Ecosys. Environ. 71: 19-35.

Bationo, B.L. (2008). Evaluation de l'efficacité agronomique des composts de déchets urbains solides de la ville de Bobo-Dioulasso. Mémoire de fin de cycle, IPR/IFRA de Katibougou, 64p et annexe

Beck T., Joergensen, R.G., Kandeler, E., Makeschin, E., Nuss, F., Oberholzer, H.R. and Scheu, S. (1997). An inter-laboratory comparison of ten different ways of measuring soil microbial carbon. Soil Biology and Biochemistry 29: 1023-1032.

Beck, R. W. (2008). Alameda County Waste Characterization Study. Alameda County, California: StopWaste.Org.

Bending, G.D., Turner, M.K., Rayns, F., Marx, M. and Wood, M. (2004). Microbial and biochemical soil quality indicators and their potential for differentiating areas under contrasting agricultural management regimes. Soil Biol. Biochem. 36: 1785–1792.

Bergmann, W. (1992). Nutritional disorders of plants. 2nd ed. Gustav Fischer Verlag, Jena, Germany.

Bertran, E., Sort, X., Soliva, M. and Trillas, I. (2004). Composting Winery waste: Sludges and grape stalks. Bioresource Technol 95: 203-208.

Birch, H. F. (1958). The effect of soil drying on humus decomposition and nitrogen availability. Plant and Soil 10 (1): 9-31.

Birch, H. F. (1964). "Mineralization of plant nitrogen following alternate wet and dry conditions". Plant and Soil, 20: 43 – 49.

Blair, J. G. and Boland, O. W. (1978). The release of P from plant material added to soil. Australian Journal of Soil Research 16: 101 – 111.

Breland, T. A. and Hansen, S. (1996). Nitrogen mineralization and microbial biomass as effected by soil compaction. Soil Biology and Biochemistry 28: 655 – 663.

Brookes, P.C., Landman, A., Pruden, G. and Jenkinson, D.S. (1985). Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biology and Biochemistry, 17: 837-842.

Brookes, P.C., Powlson, D.S. and Jenkinson, D.S. (1982). Mensurement of microbial biomass phosphorus in soil. Soil Biology and Biochemistry 14: 319-329.

Bruck, H. and Guo, S.W. (2006). Influence of N form on growth and photosynthesis of Phaseolus vulgaris L. plants. J Plant Nutr Soil Sc 169(6): 849-856

Bulluck III, L.R., Brosius, M., Evanylo, G.K. and Ristaino, J.B. (2002). Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. Appl. Soil Ecol. 19: 147–160.

Bundy, L.G. and Meisinger, J.J. (1994). Nitrogen availability indices. In: Microbiological and biochemical properties. In: Weaver, R.W., Angel, S., Bottomley, P.and Bezdicek, D. (eds). Soil Science Society of America, Madison, WI, pp. 951-984.

Buol, S. W. and Stokes. M. L. (1997). Soil profile alteration under long-term high-input agriculture. In: Buresh, R. J., Sanchez, P. A. and Calhoun, F. (eds.): Replenishing soil fertility in Africa. Special Publication No. 51. Soil Sci. Soc. Am., Madison, WI.

Burgess, M. S., Mehuys, G. R. and Madramootoo, C. A. (2002). Nitrogen dynamics of decomposing corn residue components under three tillage systems. Soil Science Society of America Journal 66: 1350 – 1358.

Cambardella, C. A., Richard, T. L. and Russell, A. (2003) Compost mineralization in soil as a function of composting process conditions. Eur J Soil Biol 39: 117–127

Campbell, C. A., Lafond, G. P., Leyshon, A. J., Zentner, R. P. and Janzen, H. H. (1991). Effect of cropping practices on the initial potential rate of nitrogen mineralization in a thin Black Chernozem. Can. J. Soil Sci. 71: 43- 53.

Campbell, C. A., Zentner, R. P., Dormaar, J. F. and Voroney, R. P. (1986). Land quality, trends and wheat production in Western Canada. Pp. 318-353. In: Slinkard, A. E. and Fowler, D. B. (eds.) Wheat production in Canada: A review. Proc. Can. Wheat Prod. Symp. Div. of Ext. and Community Relations, Saskatoon, SK. 3-5 Mar. 1986. Univ.of Saskatchewan, Saskatoon, SK, Canada.

Carol, F. (2007). Nitrogen transformations in soil. California dairy. pp 4

Carrera, L. M., Buyer, J. S., Vinyard, B., Abdul-Baki, A. A., Sikora, L. J. and Teasdale, J. R. (2007). Effects of cover crops, compost, and manure amendments on soil microbial community structure in tomato production systems, Appl. Soil Ecol. 37: 247-255.

CAST (Council for Agricultural Science and Technology) (1996). Integrated animal waste management. Task Force Report. No. 128. Council for Agricultural Science and Technology. Ames. Iowa.

Chadwick, D.R., John, F., Pain, B.F., Chambers, B.J. and Williams, J. (2000) Plant uptake of nitrogen from the organic fraction of animal manures: a laboratory experiment. Journal of Agricultural Science 134: 159-168.

Chang, C., Sommerfeldt, T. G. and Entz, T. (1990). Rates of soil chemical changes with eleven annual applications of cattle feedlot manure. Can. J. Soil Sci. 70: 673-681.

Chang, E.H., Chung, R.S. and Tsai, Y.H. (2007). Effect of different application rates of organic fertilizer on soil enzyme activity and microbial population. Soil Science and Plant Nutrition, 53: 132-140.

Chaves, B., De Neve, S., Hofman, G., Boeckx, P. and Van Cleemput, O. (2004). Nitrogen mineralization of vegetable root residues and green manures as related to their (bio) chemical composition. European Journal of Agronomy 21: 161-170.

Ciampitti, I. A. and Vyn T. J. (2012). Physiological perspectives of changes over time in maize yield dependency on nitrogen uptake and associated nitrogen efficiencies: A review. Field Crop Res 133: 48-67

Clarholm, M. and Rosswall, T. (1980). Biomass and turnover of bacteria in a forest soil and a peat. Soil Biol. Biochem. 12: 49-57.

Cleaver, K. M. and Schreiber, G. A. (1994). Reserving the spiral; the population, agriculture and environment nexus in sub-Saharan Africa. World Bank, Washington, DC.

Coyne, M. S. (1999). Soil Microbiology: An exploratory approach. Delmar Publishers, 3 Columbia Circle, Box 15015 Albany, New York 12212-5015. 462p

Crecchio, C., Curci, M., Mininni, R., Ricciuti, P. and Ruggiero, P. (2001) Short-term effects of municipal solid waste compost amendments on soil carbon and nitrogen content, some enzyme activities and genetic diversity. Biology and Fertility of Soils 34: 311-318.

Dahlin, S., Kirchmann, H. Katterer, T. Gunnarsson, S. and Bergstrom, L. (2005). Possibilities for improving nitrogen use from organic materials in agricultural cropping systems. Ambio: A Journal of the Human Environment 34(4): 288 – 295.

De Ridder, N. and van Keulen, H. (1990). Some aspects of soil organic matter in sustainable intensified arable farming systems of West African semiarid tropics. Fertilizer Research 26: 299-310.

Deenik, J. (2006). Nitrogen mineralization potential in important agricultural soils of Hawaii. Soil and crop management. College of Tropical Agriculture and Human Resources (CTAHR). http://www.ctahr.hawaii.edu/freepubs. Accessed July 2014

Donovan, G. and Casey, F. (1998). Soil fertility management in sub-Saharan Africa. Technical Paper, World Bank, Washington DC, 408.

Dudal, R. and Deckers, J. (1993). Soil organic matter in relation to soil productivity. In: Mulongoy, K., Merckx, R. (eds.), Soil organic matter dynamics and sustainability of tropical agriculture. John Wiley and Son, West Sussex, United Kingdom.

Eghball, B (2000) Nitrogen mineralization from field-applied beef cattle feedlot manure or compost. Soil Sci Soc Am J 64: 2024–2030

Eghball, B. (2002). Soil properties as influenced by phosphorus and nitrogen – based manure and compost applications. Agron. J. 94: 128 – 135.

Eghball, B. and Power, J. F. (1999). Phosphorus and nitrogen – based manure and soil compost application: Corn production and soil phosphorus. Soil Sci. Soc. Am. J. 63: 895 – 901.

Evans, L.T. (1993). Crop Evolution, Adaptation and Yield. Cambridge Univ. Press, Cambridge, England.

Ezennia, O. J. (2011). Microbial analysis of food waste composting. MSc thesis, Faculty of Biosciences, Nnamdi Azikiwe University, Awka, 78 p.

FAO, (1976). A framework for land evolution. Food and Agriculture Organization of the United Nation, Rome.

Fatondji, D, Martiusm C, Bielders, C, Vlek, P, 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. Nutr Cycl Agroecosyst 76: 203–217.

Fatondji, D. (2002). Organic amendment decomposition, nutrient release and nutrient uptake by millet (Pennisetum glaucum (L.) R.Br.) in a traditional land rehabilitation technique (zai) in the Sahel. Ecology and Development, serie N^0 1, 147p.

Fatondji, D., Martius, C., Zougmore, R., Vlek, P. L. G., Bielders, C. L., and Koala, S. (2009). Decomposition of organic amendment and nutrient release under the zai technique in the Sahel. Nutrient Cycling in Agroecosystems 85(3): 225-239.

Ferris, H., Venette, R.C. and Scow, K.M. (2004). Soil management to enhance bacterivore and fungivore nematode populations and their nitrogen mineralization function. Appl. Soil Ecol. 25: 19–35.

Fliebach, A. and Mäder, P. (2000). Microbial biomass and size-density fractions differ between soils of organic and conventional agricultural systems. Soil Biol. Biochem. 32: 757–768.

Fliebach, A., Oberholzer, H., Gunst, L. and Mäder, P., (2007). Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agric. Ecosyst. Environ. 118: 273–284.

Franzlubbers, A.J., Haney, R.L. and Hons, F.M. (1999). Relationships of chloroform fumigation-incubation to soil organic matter pools. Soil Biology and Biochemistry 31: 395 – 405.

Franzluebbers, A.J., Haney, R.L., Hons, F.M., and Zuberer, D.A. (1996). Active fractions of organic matter in soils with different texture. the drying process. As drying temperature was increased Soil Biol. Biochem. 28: 1367–1372

Gabriel, W. Q., (2010). Effect of organic and inorganic fertilizers and their combinations on the growth and yield of maize in the semi-deciduous forest zone of Ghana. MSc Thesis, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. 162 p.

Giller, K. E. (2002). Targeting mement of organic resources and mineral fertilisers: Can we match scientist fantasies with farmers realities? In: Vanlauwe B., Diels, J., Sanginga, N. and Merckx, R. (Eds), Integrated plant nutrient management in sub-Saharan Africa: From concept to practice. CAB International, Wallingford Oxon, UK, pp. 155-172.

Gladwin, C. H., Buhr, K. L., Goldman, A., Hiebsch, C., Hildebrand, P. E., Kidder, G., Langham, M., Lee, D., Nkedi-Kizza P. and Williams, D. (1997). Gender and soil fertility in Africa. In: Buresh, R. J., Sanchez, P. A. and Calhoun, F. (eds.): Replenishing soil fertility in Africa. ASA-SSSA Special Publication 51: 219. American Society of Agronomy, Madison, W1, USA.

Groffman, P.M. and Tiedje, J.M. (1989). Denitrification in north temperate forest soils: spetial and temporal patterns at the landscape and seasonal scales. Soil Biol. Biochem. 21: 613 – 620.

Guo, S, Brtick, H. and Sattelmacher, B (2002). Effects of supplied nitrogen form on growth and water uptake of French bean (Phaseolus vulgaris L.) plants. Plant Soil 239 (2): 267-275

Gutser, R., Ebertseder, T., Weber, A., Schraml, M. and Schmidhalter, U. (2005) Short-term and residual availability of nitrogen after long-term application of organic fertilizers on arable land. Journal of Plant Nutrition and Soil Science 168: 439-446.

Hadas, A, Kautsky, L. and Portnoy, R (1996). Mineralization of composted manure and microbial dynamics in soil as affected by long-term nitrogen management. Soil Biol Biochem 28: 733–738

Han, K.H., Choi, W.J., Han, G.H., Yun, S.I., Yoo, S.H. and Ro, H.M. (2004). Urea nitrogen transformation and compost nitrogen mineralization in three different soils as affected by the interaction between both nitrogen inputs. Biology and Fertility of Soils 39: 193-199.

Harris, P. J. C., Allison, M., Smith, G., Kindness, H. M. and Kelly, J. (2001). The potential use of waste-stream products for soil amelioration in peri-urban interface agricultural production systems. In: Drechsel, P.and Kunze, D. Waste composting for urban and peri-urban agriculture by IWMI and FAO.

Hartl, W. and Erhart, E. (2005) Crop nitrogen recovery and soil nitrogen dynamics in a 10-year field experiment with biowaste compost. Journal of Plant Nutrition and Soil Science 168: 781-788.

Hatice, S. U. and Nur, O. (1998). Seasonal changes in microbial biomass and enzyme activity in arable and grassland soil. http: ||www.toprk. org.tr./isd/isd-77.htm. Hatice

He, X. T., Traina, S. J. and Logan, T. J. (1992). Chemical properties of municipal solid waste composts. Journal of Environmental Quality 21: 318-329.

Heal, O.W., Anderson, J.M. and Swift, M.J. (1997). Plant litter quality and decomposition: A historical overview. In: Cadisch, G. and Giller, K.E. (eds.). Driven by nature, plant litter quality and decomposition. CAB International, Wallingford, UK, pp. 3 -30.

Holford, I. C. R. (1997). Soil Phosphorus: its measurement and its uptake by plants. Aust. J Soil Res. 35: 227 – 239.

Holmes, W. E. and Zak, D. R. (1994). Soil microbial biomass dynamics and net nitrogen mineralization in northern hardwood Ecosystems. Published in Soil Sci. Soc. Am. J. 58: 238-243.

Horwath, W. R. and Paul, E. A. (1994). Microbial biomass. In: Segoe, S. (ed) Soil Science Society of America, Madson of Soil Analysis, Part 2. Microbiological and Biochemical properties. SSSA Book Series, N^0 5.

Hue, N. V. (1995). Sewage Sludge. In: Rechcigl, J. E. (ed) Soil amendment and environmental quality. Lewis Publ., Boca Raton. FL. P. 193 – 239.

Idrissa, A.M. (2010). La simulation des composantes du rendement du mil sous la fertilization par micro - dose en utilisant le modele DSSAT. These d'Ingenieur, Faculte des Sciences Agronomiques, Universite Ibn Khaldoun, Tiaret, Algerie. 64 p.

Iglesias-Jimenez, E. and Alvarez, C.E. (1993). Apparent availability of nitrogen in composted municipal refuse. Biology and Fertility of Soils 16: 313-318.

Insam, H. D. and Domsch, K. H. (1989). Influence of microclimate on soil microbial biomass. Soil Biology and Biochemistry 21: 211-21.

Insam, H., Parkinson, D. and Domsch, K.H. (1989). Influence of macroclimate on soil microbial biomass. Soil Biol. Biochem. 21: 211-221.

Janssen, B.H. (1996) Nitrogen mineralization in relation to C:N ratio and decomposability of organic materials. Plant and Soil 181: 39-45.

Jedidi, N., Hassen, A., Van Cleemput, O. and M'Hiri, A. (2004). Microbial biomass in a soil amended with different organic wastes. Waste management and Research, 22(2): 93-99.

Joergensen, R. G. (1995). The quantitative determination of microbial biomass by the chloroform-fumigation extraction method. In: Meyer, B. (ed) Gottinger Bodenkunliche Berichte 104: 1-229.

Jones, D. I., Dennis, P. G., Owen, A. G. and van Hee, P. A. W. (2003). Organic acid behaviour in soils – misconceptions and knowledge gaps. Plant and Soil 248: 31 – 41.

Jozef, Z. (2004). Microbial biomass versus soil fertility in forest sites. Polish Journal of Ecology 52 (4): 553-561.

Kennedy, A.C. (1999). Bacterial diversity in agroecosystems, Agriculture, Ecosystems and Environment 74: 65–76.

Kim, K.D., Nemec, S., and Musson, G. (1997). Effects of composts and soil amendments on soil microflora and phytophthora root and crown rot of bell pepper, Crop Protection 16 (2): 165-172.

Kirchmann, H., Johnston Johnny, A.E. and Bergstrom, L.F. (2002). Possibilities for reducing nitrate leaching from agricultural land. Ambio 35(5): 404 – 408.

Kissel, D. E. and Smith, S. J. (1978). Fate of fertilizer nitrate applied to coastal Bermuda grass on a swelling clay soil, Soil Science Society of American Journal 42: 77-80.

Kogbe, J. O. S. and Adediran, J. A. (2003). Influence of nitrogen, phosphorus and potassium application on the yield of maize in the savanna zone of Nigeria. African Journal of Biotechnology 2 (10): 345 – 349.

Landon, J. R. (1996). Booker tropical soil manual. A handbook for soil survey and agricultural land evolution in the tropics and sub-tropics. Longman. 431 pp.

Lawlor, D.W. (2002). Carbon and nitrogen assimilation in relation to yield: mechanisms are the key to understanding production systems. Journal of Experimental Botany 53: 773−787.

Leiros, M. C., Trasar-Cepeda, C., Seoane, S. and Gil-Sotress, F. (2000). Biochemical properties of acid soils under climax vegetation (Atlantic oak wood) in an area of European temperature-humid zone (Galicia, NW Spain): General parameters- Soil Biol. Biochem. 32: 733-745.

Leonard, D. (1986). Soil, Crop, and Fertilizer Use: A Field Manual for Development Workers. Under contract with Peace Corps. 4th edition revised and expanded. United State Peace Corps. Information collection and exchange. Reprint R0008.

Linca, A., Kasno, A. and Rochayati, S. (2012). Effect of organic matter on nitrogen mineralization in flooded and dry soil. ARPN Journal of Agricultural and Biological Science, 7(8): 586-590.

Loecke, T. D., Cambardella, C. A. and Liebman, M. (2012). Synchrony of net nitrogen mineralization and maize nitrogen uptake following applications of composted and fresh swine manure in the Midwest U.S. Papers in Natural Resources. Nutr Cycl Agroecosyst 93: 65–74

Logah, V. (2010). Soil fertility and microbial biomass carbon, nitrogen and phosphorus dynamics under different amendments and cropping systems in Ghana. PhD Thesis, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. 200 p.

Logah, V., Safo, E. Y. and Quansah, C. (2011). Evaluation of nitrogen mineralization dynamics following amendments application under cropping systems on a Ferric Acrisol in Ghana. International Journal of Environmental Science and Development, 2(2): 133-137

Logah, V., Safo, E. Y., Quansah, C. and and Danson, I. (2010). Soil microbial biomass carbon, nitrogen and phosphorus dynamics under different amendments and cropping systems in the Semi-Deciduous Forest zone of Ghana. West African Journal of applied ecology 17: 121-133.

Logah, V., Ewusi-Mensah, N., Tetteh, E. N., Quansah, C. and Danso, I. (2013). Seasonal variations of soil microbial biomass under different nutrient management and cropping systems on a Ferric Acrisol in Ghana. Journal of Tropical Agriculture 51(1-2): 98-104.

Lundquist, E.J., Jackson, L.E., Scow, K.M. and Hsu, C., (1999). Changes in microbial biomass and community composition, and soil carbon and nitrogen pools after incorporation of rye into three California agricultural soils. Soil Biol. Biochem. 31: 221–236.

Lynch, J.M. (1983). Soil Biotechnology, microbiological factors in crop productivity. Blackwell Scientific Publications, Oxford.

Ma, B.L, Dwyer, L.M. and Gregorich, E.G (1999). Soil nitrogen amendment effects on seasonal nitrogen mineralization and nitrogen cycling in maize production. Agron J. 91: 1003–1009

MacDonald, N.W., Zak, D.R. and Pregitzer, K.S. (1995). Temperature effects on kinetics of microbial respiration and net nitrogen and sulfur mineralization. Soil Science Society of America Journal 59: 233 – 240.

Marschner, H. (1995). Mineral nutrition of higher plants. 2nd ed. Academic Press, San Diego, CA.

Marti, H. R. and Mills, H. A. (1991). Nutrient uptake and yield of sweet pepper as affected by stage of development and n form. J. Plant Nutr. 14(11): 1165 – 1175.

Martin-Prevel, P. J. (1989). Physiological processes related to handling and storage quality of crops. In: Proceedings of the 21st IPI Colloquium on: Methods of K research in plants, Held at Louvain-la-Neuve, Belgium, 19 – 21 June 1989. International Potash Institute, Bern, Switzerland. pp. 219 – 248.

McInter J. (1986). Constraints to fertilizer use in the Sub-Saharan Africa. In: Mokwunye, A. U. and Vlek, P. L. G. Management of nitrogen and phosphorus fertilizers in Sub-Saharan Africa (eds): 33-57. Martinus Nijhoff Publishers. Dordrecht, The Netherlands.

Mike, O' L., George, R. and Schmitt, M. (1994). Understanding nitrogen in soils. Department of Agriculture. Regents of the University of Minnesota. http://www.extension.umn.edu/agriculture/nutrient management/nitrogen/understanding-nitrogen-in-soils/. Accessed June 2014

Mills, H. A. and Jones, Jr. J. B. (1996). Plant nutrition and analysis, essential macronutrients. In: Plant Analysis Handbook II, pp. 8 – 15, Macromicro Publishing, Athens, GA.

Misra, R. V., Roy, R. N. and Hiraoka, H. (2003). On-farm composting methods. Rome: FAO. 13 p.

Misra, R.V., Roy, R.N. and Hiraoka, H. (2005). Méthodes de compostage au niveau de l'exploitation agricole. Documents de travail sur les terres et les eaux. FAO-Rome. 51 p.

Moore, P.A., Daniel, T.C. and Edwards, D.K. (2000). Reducing phosphorus runoff and inhibiting ammonia loss from poultry manure with aluminum sulfate. J. Environ. Qual. 29: 37–49.

Morel, C., Tiessen, H. and Stewart, J.W.B. (1996). Correction for P-sorption in the measurement of soil microbial biomass P by $CHCL_3$ fumigation. Soil Biology and Biochemistry 28: 1699 – 1706.

Morel, J. L., Guckert, A., Nicolardot, B., Benistant, D., Catroux, G. and Germon, J. C. (1986). Etude de l'evolution des caractéristiques physico-chimiques et de la stabilité biologique des ordures ménagères au cours du compostage. Agronomie, 6(8): 693-701.

Motavalli, P.P., Kelling, K.A. and Converse, .C (1989). First year nutrient availability from injected dairy manure. Journal of Environmental Quality 18: 180-185.

Munyabarenzi, I., Mochoge, B.E. and Nabahungu, L. (2012). Effects of farmyard manure and mineral fertilisers on maize yield and soil properties in two districts of Southern Rwanda. Third RUFORUM Biennial Meeting, Entebbe, Uganda. Research Application Summary 725-730.

Mustin, M. (1987). Le compost: gestion de la matière organique. Editions François Dubusc–Paris. 954p

Nelson, D.W. and Sommers, L.W. (1982). Total carbon, organic carbon and inorganic matter. In: Page, A.L., Miller, R.H. and Keeney, D.R. (eds.). Methods of soil analysis. Part 2. Second edition. Chemical and microbiological properties. American Society of Agronomy and Soil Science Society of America. Madison, Wisconsin USA. pp. 301 – 312.

Nevens, F. and Reheul, D. (2003) The application of vegetable, fruit and garden waste (VFG) compost in addition to cattle slurry in a silage maize monoculture: nitrogen availability and use. European Journal of Agronomy 19: 189-203.

Nguyen, T. H., and Shindo, H. (2011). Effects of different levels of compost application on amounts and distribution of organic nitrogen forms in soil particle size fractions subjected mainly to double cropping.2(3): 213-219

Nye, P. H. and Stephens, D. (1962) Soil fertility. In: Wills, J. B. Agriculture and land use in Ghana. London: Oxford University Press. ch. 7, pp. 127-143.

Oberson, A., Friesen, D.K. Morel, C. and Tiessen, H. (1997). Dertermination of P released by chloroform fumigation from microbial biomass in high P sorbing tropical soils. Soil Biology and Biochemestry 29: 1579 – 1583.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (1993). Laboratory methods of soil and plant analysis: A working manual. Tropical Soil Biology and Fertility.

Soil Science Society of East Africa. Technical Publication N_0. 1. Nairobi, Kenya. 88 pp.

Olsen, S.R. and Sommers, L.E. (1982). Phosphorus. In: Page, A.L., Miller, R.H. and Keeney, D.R. (eds.). Methods of soil analysis. Part 2. Second edition. Chemical and microbiological properties. Second edition. American Society of Agronomy and Soil Science Society of America. Madison, Wisconsin USA. pp. 403 – 448.

Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G. and Giller, K.E. (2001). Organic inputs for soil fertility in tropical agroecosystems: Application of an organic resource database. Agriculture, Ecosystems and Environment 82: 27 – 42.

Palm, C.A., Myers, R.J.K. and Nandwa, S.M. (1997). Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Buresh, R.J., Sanchez, P.A. and Calhoun, F. (eds.). Replenishing soil fertility in Africa. Soil Science of America Special Publication Number 51, Soil Science Society of America, Madison, Wisconsin1n. pp. 193 – 217.

Pascual, J.A., García, C., Hernandez, T. and Ayuso, M. (1997). Changes in the microbial activity of an arid soil amended with urban organic wastes. Biol. Fertil. Soils 24: 429-434.

Perez-piqueres, A., Edel-Hermann, V., Alabouvette, C. and Steinberg, C., (2006). Response of soil microbial communities to compost amendments. Soil Biol. Biochem. 38: 460–470

Perrenoud, S. (1993). Fertilizing for high yield potato. IPI Bulletin 8. 2nd Edition. International Potash Institute, Basel, Switzerland.

Petersen, J. (2003). Nitrogen fertilizer replacement value of sewage sludge, composted household waste and farmyard manure. Journal of Agricultural Science 140: 169-182.

Pieri, C.J.M.G. (1989). Fertility of soils: A future for farming in the West African Savannah. Springer-Verlag, Berlin, Germany.

Pierre, B. I. A., Karlheinz, M. and Charles, L. B., (2008). Integrated nutrient management of pearl millet in the Sahel combining cattle manure, crop residue and mineral fertilizer. Expl Agric. (2008), 44: 453–472.

Potash and Phosphate Institute (PPI). (2003). Effect of foliar applied monopotassium phosphate on high yielding canola and wheat grown in southern Manitoba.

Powell, J.M. (1986). Manure for cropping: a case study from central Nigeria. Experimental Agriculture 22: 15–24.

Quinones, M. A., Borlaugh, N. E. and Dowswell, C. R. (1997). A fertilizer-based green revolution for Africa. In: Buresh, R. J., Sanchez, P. A. and Calhoun, F. (eds). Replenishing soil fertility in Africa. Soil Science Society of America Special Publication 51, Madison, USA. Pp 81-95.

Ramamurthy, V. and Shivashankar, K. (1996). Residual effect of organic matter and phosphorus on growth, yield and quality of maize (Zea mays). Indian Journal of Agronomy 41: 247 – 251.

Reynolds, M., Calderini, D., Condon, A. and Vargas, M. (2007). Association of source/sink traits with yield, biomass and radiation use efficiency among random sister lines from three wheat crosses in a high-yield environment. Journal of Agricultural Science 145: 3−16.

Ribereau-Gayon, J. and Peybaud, E. (1982). Ciencias y técnicas de la viña: Tratados de ampeología. Tomo I: Biología de la viña. Suelos de Viñedo, Editorial Hemisferio Sud S.A., Argentina.

Richard, T. (1996). The effect of lignin on biodegradability. In: Cornel composting (available at http://www.cfe.cornell.edu/compost/calc/lignin.htnl. Accessed May 2014.

Rogers, B.F., Krogmann, U. and Boyles, L.S. (2001) Nitrogen mineralization rates of soils amended with nontraditional organic wastes. Soil Science 166: 353-363.

Roland J. Buresh, P., Sanchez, A. and Frank, C. (1997). Replenishing soil fertility in Africa. SSSA Special Publication Number 51 Soil Science Society of America American Society of Agronomy Madison, Wisconsin, USA. pp 264

Runge, M. (1983). Physiology and ecology of nitrogen nutrition. Physiological Plant Ecology 111. 12: 163- 200.

Rynk, R., van de Kamp, M., Willson, G.B., Singley, M. E., Richard, T. L., Kolega, F. R., Gouin, L., Laliberty Jr., Kay, D., Murphy, D.W., Hoitink, H.A.J. and Brinton, WF. (1992). On-farm composting. Ithaca, NY: Northeast Regional Agricultural Engineering Service.

Sagna, M.A., and Marchal, D., (1992). Fertilisation. Cours n°51 Centre d'Appui pour le Recyclage des Agents techniques. Bureau de Pédologie & Programme Engrais FAO du Sénégal.92p

Saison, C., Degrange, V., Oliver, R.., Millard, P., Commeaux, C., Montange, D. and Le Roux, X. (2006). Alteration and resilence of the soil microbial community following compost amendment: effects of compost level and compost-borne microbial community, Environmental Microbiology 8 (2): 247-257.

Sanchez, P. A. (1997). Changing tropical soil fertility paradigms: from Brazil to Africa and back. In: Monis, A. C. et al. (eds): Plant – soil interactions at low pH. Brazilian Society of soil Science. Piracicaba, SP, Brazil. Pp. 19 – 28.

Sanchez, P.A., Sheperd, 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. In: Buresh, R.J., Sanchez, P.A. and Calhoun, F. (eds.). Replenishing soil fertility in Africa. Soil Science Society of America Special Publication Number 51, Madison, Wisconsin USA. pp. 1 – 46.

Sanders, J., Shapiro, B.I. and Ramaswamy, S. (1996). The Economics of agricultural technology in Semi-Arid Sub-Saharan Africa, Johns Hopkins University Press, Baltimore, Maryland USA. 303p.

Sanginga, N. and Woomer, P. L. (2009). Integrated soil fertility management in Africa: Principles, practices and developmental process. ISBN: 978-92-9059-261-7. pp 263.

Schimel, D.S, (1986). Carbon and nitrogen turnover in adjacent grassland and cropland ecosystems. Biogeochemistry 2: 345-357.

Schlesinger, W. H. (1977). Carbon balance in terrestrial detritus. Annual Review of Ecology and Systematics 8: 51-81.

Schnürer, J., Clarholm, M. and Rosswail, T. (1985). Microbial biomass and activity in agricultural soil with différent organic matter content. Soil Biology and Biochemistry. 17: 611 – 618.

Schorth, G. (2003). Decomposition and nutrient supply from biomass. In: Schorth, G. and Sinclari, F.L. (eds). Trees, crops and soil fertility: concepts and research methods. CABI Publishing, ISBN - 0851995934.

Scott, W. J. (1957). Water relations of food spoilage microorganisms. Advances in Food Research 7: 83 127.

Seneviratne, G., Van Holm, L.H.J. and Kulasooriya, S.A. (1998). Quality of different mulch materials and their decomposition and N release under low moisture regimes. Biology and Fertility of Soils 26: 136 – 140.

Shai, R.W. and Norton, J.M. (2000). Microbial control of nitrate concentrations in an agricultural soil treated with dairy waste compost or ammonium fertilizer. Soil Biology and Biochemistry, 32: 1453-1457.

Shannon, D., Sen, A.M. and Johnson, D.B. (2002). A comparative study of the microbiology of soils managed under organic and conventional regimes. Soil Use Management 18: 274- 283.

Shanti, K. V. P., Rao, M. R., Reddy, M. S. and Sarma, R. S. (1997). Response of maize (*Zea mays*) hybrid and composite to different levels of nitrogen. Indian J. Agric. Sci. 67: 424 - 425.

Shi, W., Norton, J.M., Miller, B.E. and Pace, M.G. (1999). Effects of aeration and moisture during windrow composting on the nitrogen fertilizer values of dairy waste composts. Appl Soil Ecol 11: 17–28

Sikora, L.J. and Yakovchenko, V. (1996). Soil organic matter mineralization after compost amendment. Soil Science Society of America Journal 60 (5): 1401-1404.

Singh, J. P. and Trehan, S. P. (1998). Balanced fertilization to increase the yield of potato. In: Proceedings of the IPI-PRII-PAU Workshop on: Balanced Fertilization in Punjab Agriculture, held at Punjab Agricultural University, Ludhiana, India. pp 129 – 139.

Singh, J.S., Raghubanshi, A.S., Singh, R.S. and Srivastava, S.C. (1989). Microbial biomass acts as a source of plant nutrients in dry tropical forest and savanna. Nature (London) 338: 499 – 500.

Smith, J.L. and Paul, E.A., (1990). The significance of soil microbial biomass estimations. In: Bollag, J.M. and Stotzky, G. (eds.), Soil Biochemistry, vol. 6. Marcel Dekker, Inc., New York, NY, pp. 357–396.

Snapp, S. S. and Borden, H. (2005). Enhanced nitrogen mineralization in mowed or glyphosate treated cover crops compared to direct incorporation. Plant and Soil, 270(1): 101-112.

Sodhi, G.P.S., Beri, V. and Benbi, D.K. (2009). Soil aggregation and distribution of carbon and nitrogen in different fractions under long-term application of compost in rice-wheat system. Soil & Tillage Research 103: 412- 418.

Sommerfeldt, T. G. and Chang, C. (1985). Changes in soil properties under annual applications of feedlot manure and different tillage practices. Soil Sci. Soc. Am. J. 49(4): 983 - 987.

Soudi, B. (2001). Compostage des déchets ménagers et valorisation du compost, Cas des petites et moyennes communes au Maroc, Actes Editions, ISBN: 9981-801-47-X, Maroc, 104 p.

Sparling, G. P., Feltham, C. W., Reynolds, J., West, A.W. and Singleton, P. (1990). Estimation of soil microbial carbon by fumigation – extraction method. Use on soils of high organic matter content, and a reassessment of the KEc-factors. Soil Biology and Biochemistry 22: 301- 07.

Srivastava, S.C. (1992). Microbial C, N, and P in dry tropical soils: Seasonal changes and influence of soil moisture. Soil Biol. Biochem. 24: 711 -714.

Strong, D. T., Sale, P. W. G. and Helyar, K. R. (1999). The influence of the soil matrix on nitrogen mineralization and nitrification. III. Predictive utility of traditional variables and process location within the pore system. Australia Journal of Soil Research 37: 137 – 149.

Swift, M. J. and Woomer, P. (1993). Organic matter and the sustainability of agricultural systems: definition and measurement. In: Mulongoy, K. and Merckx, R. (eds.), Soil organic matter dynamics and sustainability of tropical agriculture. John Wiley and Son, West Sussex, United Kingdom.

Tabo, R., Bationo, A., Diallo, Maimouna, K., Hassane, O., and Koala, S. (2005a). Fertilisation par micro dose pour la prospérité du petit paysan au sahel : rapport final, ICRISAT Niger, 28p.

Tabo, R., Kanlambigue, A. M. and Maatman, A. (2005b). Projet USAID TARGET sur la fertilisation par micro dose pour la prospérité des petits producteurs au sahel : Atelier de formation sur la transposition à grande échelle (schaling-up) de la technologie de la fertilisation par micro dose 20-23 janvier 2004, Ouahigouya Burkina Faso, ICRISAT Niger, 28P

Tanaka, M. and Shindo, H. (2009). Effect of continuous compost application on carbon and nitrogen contents of whole soils and their particle size fractions in a field subjected mainly to double cropping. In: Pereira, J.C. and Bolin, J.L., (eds.), Composting: processing, materials and approaches, Nova Science Publishers, New York, 187- 197.

Tel, D. A. and Heseltine, C. (1990). The analyses of KCl soil extracts for nitrate, nitrite and ammonium using a TRAACS 800 analyzer. Commun. Soil Sci. Plant Anal. 21: 1681–1688.

Tiessen, H., Cuevas, E. and Chacon, P. (1994). The role of soil organic matter in sustaining soil fertility. Nature 371: 783-785.

Toyota, K. and Kuninaga, S. (2006). Comparison of soil microbial community between soils amended with or without farmyard manure, Appl. Soil Ecol. 33: 39–48.

Treonis, M., Austin, E. E., Buyer, J. S., Maul, J. E., Spicera, L. and Zasada, I. A. (2010). Effects of organic amendment and tillage on soil microorganisms and microfauna. Appl. Soil Ecol. 46: 103–110.

Tsai, C.Y., Dweikat, I., Huber, D. M. and Warren, H. L. (1992). Interrelationship of nitrogen nutrition with maize (*Zea mays*) grain yield, nitrogen use efficiency and grain quality. J. Sci. Food Agric. 58: 1-8.

Vance, E. D., Brookes, P. C. and Jenkinson, D. S. (1987). An extraction method for measuring soil microbial biomass carbon. Soil Biology & Biochemistry 19: 703–707.

Vanlauwe, B. (2004). Integrated soil fertility management research at Tropical Soil Biology and Fertility of Soil (TSBF): the framework, the principles, and their application. In: Bationo, A. (ed) Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Academy Science Publishers, Nairobi

Vanlauwe, B., Wendt, J. and Diels, J. (2001). Combined application of organic matter and fertiliser. In: Tian, G., Ishida, F., Keatinge, J.D.H. (eds.), Sustaining soil fertility in West Africa. Soil Science Society of America and American Society of Agronomy, Madison, WI, USA. pp. 247–279.

Verhallen, A. and LeBoeuf, J. (2006). Comprendre l'azote dans le sol. Minister de l'agriculture et de l'environnement, Ontario Canada http://www.omafra.gov.on.ca/french/crops/facts/info_nitrogen.htm). Accessed March 2014.

Verhoef, H. A. and Brussaard, L. (1990). Decomposition in natural and agroecosystems: The contribution of soil animals. Biochemistry 11: 175 – 211.

Waas, E. (1996). Valorisation des déchets organiques dans les quartiers populaires des villes africaines. Projet FNRS N°5001-038104. Module 7, développement et environnement. Programme prioritaire SKAT l43 p.

Wander, M. M., Hendrick, D. S., Kaufinan, D., Traina, S. J., Stinner, B. R., Kehrmeyer S. R. and White, D. C. (1995). The functional significance of the microbial biomass in organic and conventionally managed soils. Plant Soil 170: 87- 97.

Wayne, P., Daniel, M. and Jessica, S. (2014). Total organic carbon. http://www.soilquality.org.au/factsheets/organic-carbon. Accessed July 2014.

William, T. O., Powell, J. P. and Fernandez-Rivera, S. (1995). Manure availability in relation to sustainable food crop production in semi-arid West Africa: Evidence from Niger. Quarterly J. Internat. Agric 28: 351–364.

Wood, M. (1991). Biological aspects of soil protection, Soil Use Manage, 7: 130–136.

Wu, J., Joergensen, R. G., Pommerening, B., Chaussod, R. and Brookes, P. C. (1990). Measurement of soil microbial biomass C by fumigation-extraction - An automated procedure. Soil Biol. Biochem. 22: 1167-1169.

Xie, R. J. and MacKenzie, A. F. (1986). Urea and manure effects on soil nitrogen and corn dry matter yields. Soil Sci. Soc. Am. J. 50: 1504 - 1509.

Zak, J. C., Willig, M. R., Moorhead, D. L., and Wildman, H. G. (1994). Functional diversity of microbial communities – a quantitative approach. Soil Biol. Biochem. 26: 1101–1108.

Zwart, K. (2003). Fate of C and N pools - experience from short and long term compost experiments. In: Anon., Applying composts benefits and needs, Brussels, Federal Ministry of Agriculture, Forestry, Environment and Water Management, Austria, and European Communities, 77-86.

APPENDIX

Appendix 1a

Plate 1: Millet crop under 150 g compost + mineral fertilizer application during the study period at N'Doungua

Appendix 1b

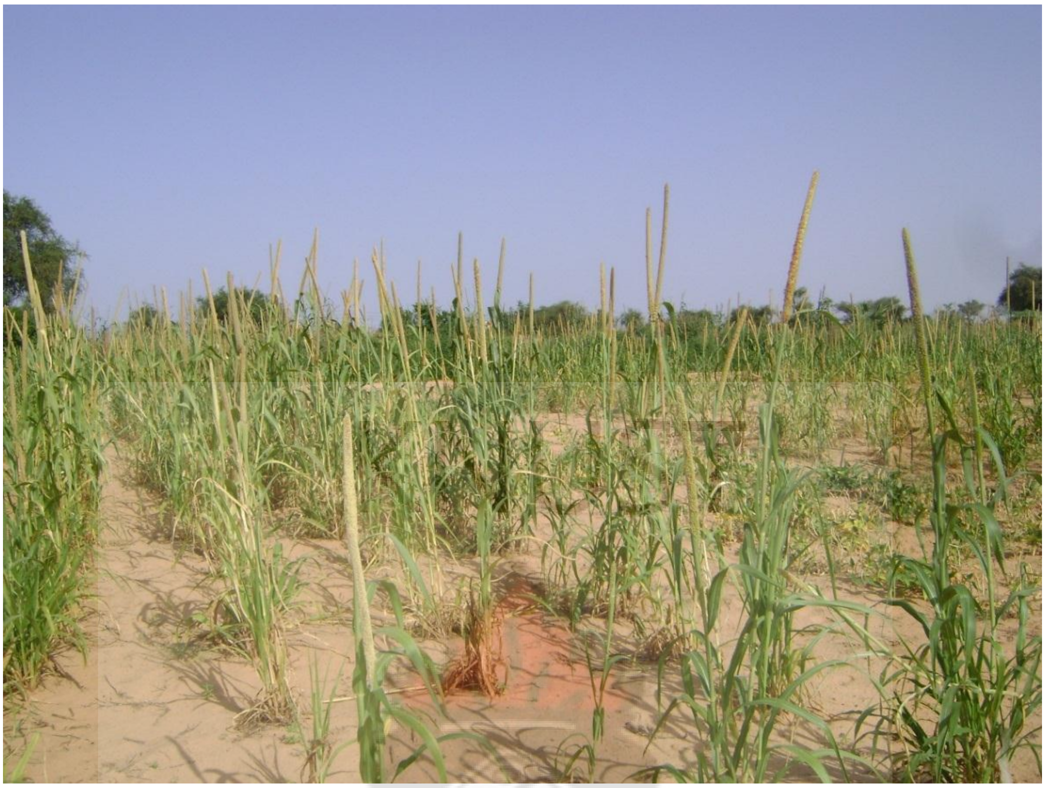

Plate 2: Millet crop under the control at N'Dougua

Appendix 1c

Plate 3: Millet crop under 300 g compost application during the study period

Appendix 2

Table 1: Daily rainfall data at N'Doungua

	Rainfall (mm)		
Days	**July**	**August**	**September**
1	16.5	29.3	0
2	0	6.4	0
3	0	0	0
4	5.9	0	0
5	0	22	1.1
6	9.8	18.8	0.1
7	1.6	0.5	1.9
8	0	4	0
9	2.5	0.4	0
10	5.4	15.9	0
11	0	15.4	1.2
12	0	1	0
13	0	0	20.2
14	17.5	18.6	0
15	3.4	3.1	0*
16	0	0	0
17	0	12.1	0
18	0	3.3	0
19	3.8	0.8	0
20	0	21	0
21	0	0	0
22	0	38.2	0

23	0	0	0
24	0	0.7	0
25	0	0.9	0
26	0	39.2	0
27	0	1.1	0
28	3.6	0	0
29	4.9	45.7	0
30	1.7	0	0
31	12.5	3.8	

*12th Week sampling