COMPOSTING MILLET GLUME FOR SOIL FERTILITY IMPROVEMENT AND MILLET/COWPEA PRODUCTIVITY IN SEMI-ARID ZONE OF NIGER

BY

BACHIR BOUNOU ISSOUFA,

B.Sc. Agriculture (2009)

M.Sc. Environmental Protection (2011)

SEPTEMBER, 2015

COMPOSTING MILLET GLUME FOR SOIL FERTILITY IMPROVEMENT AND MILLET/COWPEA PRODUCTIVITY IN SEMI-ARID ZONE OF NIGER

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

DOCTOR OF PHILOSOPHY
IN
SOIL SCIENCE

BY

BACHIR BOUNOU ISSOUFA

, SEPTEMBER, 2015

DECLARATION

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

BACHIR BOUNOU Issoufa	…….………..	..…………..........
Student: PG 20256557	Signature	Date

Certified by:

Prof R.C. Abaidoo	…….………..	..……………......
Supervisor	Signature	Date

Certified by:

Dr. NANA Ewusi-Mensah	…….……….	……………….....
Co-supervisor	Signature	Date

Certified by:

Dr. A. K. Saidou	…….………..	........08/10/2015.......
Co-supervisor	Signature	Date

Certified by:

Dr. Enoch A. Osekere	…….………..	….………………......
Head of Department	Signature	Date

DEDICATION

This work is dedicated to my parents BACHIR BOUNOU and ZOULEY HABOU who showed me the way to success and encouraged me in my exploration for this higher degree.

ACKNOWLEDGEMENTS

My cordial gratitude goes to my supervisor Prof R.C. Abaidoo, for his advice, guidance and his continuous support throughout this work, to Dr. Nana EwusiMensah and Dr. A. K. Saidou for their assistance in the supervision.

My special gratitude goes to Prof. E.Y. Safo, Rev. Prof. Mensah Bonsu and Prof. C. Quansah of the Kwame Nkrumah University of Science and Technology (KNUST), Dr. Sabiou Mahaman, Dr. Adam Mamadou, Dr. Aboubacar Malam Massou, Dr. Aboubacar Ichaou and Salou Moussa of *Institut National de Recherche Agronomique du Niger* (INRAN), Dr. Abdoulaye Mahamadou of Ministry of cooperation and foreign affair for their valuable encouragement towards successful completion of this work. My profound gratitude also goes to my colleagues of AGRA-PhD programme of the Department of Crop and Soil Sciences, KNUST, for the wonderful time that we shared together.

I acknowledge the support of the Alliance for Green Revolution in Africa (AGRA) through its Soil Health Program for the sponsorship and to various staff from AGRA who supported me. My special thanks go to Dr. Bashir Jama, Dr. Mary Rariera and Mrs. Mary Yaodze for their interest in my work. Finally, I cannot forget the support provided during the field work by Laouali Iro, Mahamadou Bonwaré, staff of the *Institut National de Recherche Agronomique du Niger* (INRAN), Maman Daouda and Ali Neino from Dan Saga village. I deeply appreciate the moral support, patience and encouragement offered by my wife and daughter, parents, brothers and sisters during this programme. Lastly, I give thanks to Almighty Allah, for granting me the mercy to endure the rigour of this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Declining soil fertility is among the most limiting factors for improving crop production in the Sahel. In Niger, organic resources are unavailable due to other competitive uses. However, millet glume (residues left after threshing of millet) is readily available in most villages of Niger and represents a potential source of reusable organic material. Nevertheless, the low decomposition rate of millet glume constraint its direct-use as an organic amendment. This study therefore focused on valorising millet glume for improving soil fertility and millet/cowpea productivity in semi-arid zone of Niger. The study consisted of five parts: (i) exploration of the indigenous knowledge related to farmer management of millet glume, (ii) decomposition and nutrient release pattern of millet glume-based compost (MGBcompost), (iii) changes in soil chemical and microbial biomass C, N, P induced by combined use of MGB-compost and mineral fertilizer, (iv) influence of combined application of MGB-compost and mineral fertilizer on millet/cowpea yields and (v) economic benefit of MGB-compost and mineral fertilizer application under millet/cowpea based cropping systems in Niger.

To explore the indigenous knowledge relating to farmers‟ management of millet glume, structured questionnaires were administrated in Dan Saga village, District of Aguié. Litterbags and leaching tube incubation experiments were used under field and laboratory conditions, respectively to monitor the decomposition and nutrient release pattern of the MGB-compost. A two-year field experiment was also conducted during the 2013 and 2014 cropping seasons to evaluate the potential of combined application of MGB-compost and mineral fertilizer on soil chemical and microbiological properties, millet/cowpea yields and economic benefit. The treatments used consisted

of a factorial combination of three (3) rates of MGBcompost (C_0, C_{150} and C_{300} g $hill^{-1}$) and three (3) rates of mineral fertilizer (0 % RR, 50 % RR and 100 % RR kg ha^{-1}; RR = recommended rate) and replicated four times.

Composting millet glume in a 2:1 ratio (2 parts of millet glume: 1 part of goat manure) improved markedly millet glume N content by 43 % and P content by 138 %. Half - life of 4.65 weeks was recorded for MGB-compost relative to 12.38 weeks for millet glume. MGB-compost released 87 % and 90 % of its total N and P contents, respectively by the end of 10 weeks of decomposition. Soil microbial biomass P was on average 2.4 times higher on MGB-compost amended plots relative to sole N and P fertilizers treated plots. The increased microbial biomass P resulted in 223 % increase in available P on MGB-compost amended plots. Application of sole MGB-compost increased millet and cowpea grain yields by 187 kg ha^{-1} (21 %) and 163 kg ha^{-1} (20 %), respectively over the sole application of N and P fertilizers. However, the combined application of MGB-compost and N and P fertilizers increased millet and cowpea grain yields by 462 kg ha^{-1} (51 %) and 616 kg ha^{-1} (76 %), respectively over the sole application of N and P fertilizers. Combined use of MGB-compost with N and P fertilizers did not increase the Value Cost Ratio (VCR) for millet. However, the VCR for cowpea was 4.4 for MGB-compost treated plot. The study concluded that millet glume could serve as an alternative organic material for soil fertility management and for increased millet/cowpea production. It is therefore recommended that combined application of MGB-compost and N and P fertilizers could be used to reduce 50 percent mineral fertilizer investment currently made by smallholder farmers in Niger.

CHAPTER ONE

1.0 Introduction

1.1 Context and justification

The Semi-Arid Sahelian zone of West Africa remains one of the poorest regions of the world due to several constraints to agricultural development (Tabo *et al.*, 2007). In West Africa, soils and climate impose enormous constraints to agricultural production (Ouendeba *et al.*, 2002). Niger is one of the Sahelian West Africa countries, where soil fertility and rainfall are the most limiting factors for agricultural production. In Niger, crops are grown on predominantly sandy soils, which are deficient in primary nutrients, particularly phosphorus (P) and nitrogen (N) (Bationo *et al.*, 1998). Nitrogen inputs can naturally be available through biological N fixation and the decomposition of crop residues and other organic compounds in the soil.

However, P inputs need to be applied in order to improve the available soil P status.

Despite the constraints, agriculture remains the main economic activity of Niger. Agriculture occupies 80 % of the active population and contributes to 41 % of the gross domestic product (CIP/SDR, 2007). Manyame (2006) reported that farmers in Niger rely mainly on rain-fed agriculture to grow pearl millet [*Pennisetum glaucum* (L.) R. Br.] and sorghum (*Sorghum bicolor* (L.) Moench) as monocrops or intercrops with cowpea [*Vigna unguiculata* (L.) Walp]. However, average grain yields of millet (350 kg ha^{-1}) and cowpea (246 kg ha^{-1}) under such subsistence farmer management approaches are considered extremely low (RGAC, 2008).

In the search for solutions to the problems of low soil fertility and crop yields exacerbated by increasing population growth rates, Kihara *et al.* (2007) proposed the use of inorganic fertilizer to increase soil fertility but these often cause problems of acidity and toxicity when applied alone. Inorganic fertilizer is not usually affordable to a large segment of smallholder farmers (Oyedeji *et al.*, 2014). Consequently, Buerkert *et al.* (2000) and Jaja and Ibeawuch (2015) proposed the combined application of inorganic fertilizer and organic resource as an appropriate strategy to ameliorate soil fertility decline and improve crop productivity. However, in Niger, most of the organic resources are not readily available due to other competitive uses (Powell and Mohamed-Saleem, 1987). In addition, Fatondji *et al.* (2009) reported that organic resources have poor quality and low nutrient contents.

Millet glume (residues left after threshing of millet) represents a potential source of organic materials. Millet glume is readily available in most villages of Niger, the second world largest producer of millet (IRD, 2009). Millet glume contains macro nutrients (nitrogen, phosphorus, potassium, calcium and magnesium) and micro nutrients (zinc, iron, manganese and copper) (Tarfo *et al.*, 2001). However, the low decomposition rate of millet glume constraints its direct-use as an organic amendment. The application of organic materials as fertilizer for sustaining crop productivity has recently received more attention (Arif *et al.*, 2015). Organic sources supply organic matter and also increases the fertility status of soil (Mohammadi *et al.*, 2012). In search for solution to the poor fertility status of soils, farmers in Niger have already started using millet glume based-compost (MGB-compost) as soil amendment (Amoukou *et al.*, 2007). Generally, compost has the advantage of improving soil quality and crop yields through increased soil‟s micro-nutrients availability (Wiart, 2000), and thus is appropriate for sustainable agriculture in resource poor farming communities (FAO, 2006). However, studies geared towards enhancing the quality of MGB-compost and its contribution to soil and crop productivity are not available to both researchers and farmers in Niger.

1.2 Objectives of the study

The overall objective of this study therefore was to explore farmers management strategies for using millet glume and determine the contribution of MGB-compost, phosphorus and nitrogen fertilizers on soil fertility and millet/cowpea productivity in Niger. The specific objectives were to:

i. explore indigenous knowledge relating to farmer management of millet glume in the Sahelian zone of Niger; ii. investigate the decomposition and nutrient release pattern of MGB-compost; iii. evaluate the changes in soil chemical and microbial biomass C, N, P induced by combined use of MGB-compost, nitrogen and phosphorus fertilizers; iv. assess the influence of combined application of MGB-compost, nitrogen and phosphorus fertilizers on millet/cowpea yields;

v. appraise the economic benefits of MGB-compost, nitrogen and phosphorus fertilizers application under millet/cowpea based cropping systems in Niger.

The above specific objectives were based on the null hypothesis that, the management of millet glume through composting and the complementary application of MGB-compost, nitrogen and phosphorus fertilizers will improve soil fertility and increase millet/cowpea productivity.

CHAPTER TWO

2.0 Literature review

2.1 Soil fertility management practices among farmers in Niger

In the Sahelian zone of West Africa, farmers have used traditional fallow practices in an attempt to restore soil fertility. Recently however, long-term fallows are less frequently employed, mainly because population increases have had negative impact on land use in the region (De Rouw and Rajot, 2004). Population and growth rate in Niger are estimated at 17,129,076 inhabitants and 3.9 %, respectively (INS, 2013).

The normal fallow practices used to have duration of more than 15 years (Wezel and Haigis, 2002) but Schlecht and Buerkert (2004) reported that, in West Niger, farmers practicing fallows did so for 1 to 3 years which is shorter compared with 4.9 years reported by Hiernaux and Ayantunde (2004) working in the same area. Wezel and Haigis (2002) suggested that the current short-term fallows are not sufficient to restore soil fertility and they advised that farmers in Niger should continue keeping land fallow for more than 15 years in order to sufficiently increase the soil organic matter (OM) levels. This recommendation is not feasible because of the pressure of population growth on land. For this reason, more studies are necessary to design other soil fertility practices that are affordable and conveniently adoptable by farmers.

McIntire *et al.* (1992) reported numerous studies on improvement of soil fertility and crop productivity in the region. However, the majority of these studies focused on technical aspects of the application of various amounts such as crop residues, livestock manure, household waste, incorporation of legumes and agroforestry used singly or in combination with mineral fertilizer (Buerkert *et al.*, 2000; Schlecht *et al.*, 2006; Suzuki *et al.*, 2014). This approach has been criticized recently for the limited consideration of farmers‟ management strategies and the socioeconomic rationales behind the adoption of these approaches (Scoones and Toulmin, 1998). The principal constraint of all these practices is the availability of the organic material. In response to the organic matter related constraints to crop productivity in the Aguié District, farmers began exploring the usefulness of millet glume after composting (Amoukou *et al.*, 2007) but little is known about farmers‟ indigenous knowledge relating to millet glume management in semi-arid zone of Niger.

2.2 Socio-economic factors affecting the adoption of soil fertility management technologies

Farmers in West Africa are reluctant to adopt soil fertility technologies (Floquet *et al.*, 2001; Afomasse *et al.*, 2004; Schlecht *et al.*, 2006). Technology adoption largely depends to a large extent on socio-economic factors (Dent *et al.*, 1995; Bationo *et al.*, 1998; Murwira, 2003). Despite the recognized need to apply chemical fertilizer for high yields, the use of mineral fertilizer in Niger is limited by lack of capital, inefficient distribution systems, poor enabling policies and poor knowledge (Bationo and Ntare, 2000). In addition, the total labour needs and costs of technology are also real challenges for farmers. Labour needs are classified as low for corralling and intermediate for the practices of mulching and mineral fertilizer application, but are high for the “zai” technique, compost making and hand-spreading of compost and for the application of household waste and farmyard manure. Therefore, the scarcity of reliable labour and cost estimates for these technologies complicate the evaluation of their attractiveness and in fact, their neglect is seen as a major cause for the nonadoption of technologies (Bationo *et al.*, 1998).

2.3 Sources and management of organic resources

In sustainable agriculture, land application of organic materials is extensively practiced. These materials are vital resources for replenishing soil organic matter and for supplying major nutrients. Organic materials added to soils contain a wide range of carbon (C) compounds that vary in rates of decomposition. The biological breakdown of the added organic material depends on the rate of degradation of C contained in the material (Reddy *et al.*, 1980; Mafongoya *et al.*, 2000; Chaudhary *et al.*, 2014). Variation in environmental factors, however, may cause change in the decomposition rates of organic materials in soils. Of these factors, aeration, moisture content, temperature, pH, substrate specificity, and available minerals have been reported to be most important. Also, decomposition rates vary among organic materials, depending on their content of N, soluble C, lignin, and various carbohydrates (Reinertsen *et al.*, 1984; Janzen and Kucey, 1988; Dossa *et al.*, 2009; Chaudhary *et al.*, 2014). In addition to plant residues, the sources of organic nutrients in soils include animal manures, sewage sludge, other industrial wastes and compost.

2.3.1 Factors affecting decomposition of crop residues

Recycling crop residues may provide nutrients necessary to reduce N depletion in fertile soils (Sanchez *et al.*, 1997; Diack *et al.*, 2000). In general, the application of crop residues increased yields, but in many cases yield tended to decline with application of only crop residues (Traore and Harris, 1995; Laryea *et al.*, 1995). Bekunda *et al.* (1997) reported that crop residues were generally less effective than animal manure as sources of nutrients. Application of residues with high C:N ratio to soils can lead to short-term N deficiency as a result of N immobilization. Crop residues of poor quality that are low in N content, such as cereal stovers, are the major sources of organic materials produced in most smallholder food production systems in Africa and the recycling of the cereal stover to cropped lands may help to maintain soil organic matter contents, or increase them in degraded soils (Giller *et al.*, 1997; Schlecht *et al.*, 2006).

Availability of N from crop residues for plant growth depends on the decomposition rates and their synchronization with crop demand (Muza and Mapfumo, 1999; Whitbread *et al.*, 2004). The ammonium - N formed during the decomposition process is relatively immobile and is subject to nitrification under aerobic conditions, leading to the formation of nitrate - N, which is a relatively mobile form (Mekonnen *et al.*, 1997; Purnomo *et al.*, 2000). The alternative approach for avoiding problems of N deficiency in crops sown soon after residue incorporation is to compost cereal stovers, because it helps improve the quality of soil amendments (Giller *et al.*, 1997).

2.3.2 Factors affecting decomposition of manure

The slower rates of manure decomposition lead to low availability of nutrients to the crops and consequently low yields. Indeed, manure with lower N concentration compared with other organic inputs can release N slowly due to a higher C:N ratio (Kimani *et al.*, 2004). However, manure behaves differently from plant materials because it has already been subjected to first-stage of decomposition when passing through the digestive system of animals, rendering the substrate less subject to nutrient immobilization (Sanginga and Woomer, 2009). Organic anions produced during decomposition of farmyard manure can also cause an increase in the pH of soil through removal of the associated protons (Whalen *et al.*, 2000).

Many decomposition studies have evaluated N mineralization rates of various animal manures (Esse *et al.*, 2001; Fatondji *et al.*, 2009; Fening *et al.*, 2010a). Bitzer and Sims (1988) reported that N mineralization from 20 poultry manure heaps averaged 66 % of organic N over 140 days‟ incubation, but rates varied widely among manure heaps. Chae and Tabatabai (1986) found similar results in 26 weeks laboratory incubation, achieving 53 % mineralization of chicken manure compared with only 31 % for horse manure. Decomposition and nutrient release of the cattle manure showed immobilization of total N during the first four weeks (Fening *et al.*, 2010a). Also, Esse *et al.* (2001) and Fatondji *et al.* (2009) reported that termites played an important role in decomposition and nutrient release pattern of manure in sandy soil of Niger. The authors showed that manure decomposition was faster on crusted than on sandy soils and manure decomposition proceeded two to three times faster than that of millet stalks.

2.3.3 Composting

Composting is defined as the transformation of raw organic materials into biologically stable, humic substances (Cooperband, 2000). During composting, microorganisms transform organic matter into carbon dioxide (CO_2), biomass, thermoenergy (heat) and humus-like end-product. Tuomela *et al.* (2000) reported that organic substrates, bulking agents and amendments used in composting are mostly derived from plant material. The main components of the organic matter are carbohydrates (e.g. cellulose), proteins, lipids and lignin. The capacity of microorganisms to assimilate organic matter depends on their ability to produce the enzymes needed for degradation of the substrate.

Factors that affect the aerobic compost process include: substrate type, aeration, temperature, lignin and polyphenol contents and pH (Golueke, 1992; Palm *et al.*, 2001; Misra *et al.*, 2003; Nolan *et al.*, 2011). Carbon, micronutrients and certain trace elements are substrates for microorganisms‟ energy and growth, respectively also influence the compost process (Tuomela *et al.*, 2000). The optimum moisture content for composting is 40 to 60 % (Lekasi *et al.*, 2003).

In contrast, Eklind and Kirchmann (2000) demonstrated that nutrients are lost during composting and may induce environmental problems. Moreover, the loss of nutrients is an agronomic problem for organic farmers who wish to maximize the fertilizing effect from their compost particularly on organic farms where nitrogen is scarce. The quality and quantity of the organic residues affect the rates of composting and the characteristics of the finished products. For example, when the carbon to nitrogen ratio (C:N) of the organic matter is about 25, transformation of the organic material proceeds rapidly with a high degree of efficiency of N from compost through ammonia volatization. Wider C:N ratios (> 40) promote immobilization of available

N in the compost, slowing the rate of decomposition (Golueke, 1992; Haynes *et al.*, 2015). Therefore, addition of mineral N and P can enhance more rapid decomposition and enrichment of the low quality residues.

2.3.3.1 The composting process

Under optimal conditions, composting proceeds through three phases: (1) the mesophilic phase, (2) the thermophilic phase, which can last from a few days to several months, and (3) the cooling and maturation phase which lasts for several months. The first micro-organisms to colonize the compost heap are of mesophilic group of bacteria, actinomycetes, fungi and protozoa. These microorganisms in compost piles tend to increase during the first 25 days of the composting process (Hassen *et al.*, 2001). During this phase, the temperature grows between 10 and 45 ºC (Cooperband, 2000) and break down easily degradable components such as sugars and amino acids (Peigné and Girardin, 2004). Organic fresh matter degradation starts as soon as the compost heap is made, and because of the oxidative action of microorganisms, the temperature increases. Despite a drop in pH at the very beginning of composting, the degradation of acids brings about a pH increase. When the temperature reaches 45 – 50 ºC, thermophilic microorganisms replace mesophilic ones (Peigné and Girardin, 2004). This important step occurs between 30 to 110 days of the composting process (Hassen *et al.*, 2001). The second phase is called the thermophilic phase and can last several weeks. It is the active phase of composting were most of the organic matter is degraded and consequently most oxygen is consumed. According to Tuomela *et al.* (2000), lignin degradation starts during this phase. Indeed, the optimum temperature for thermophilic micro-fungi and actinomycetes which mainly degrade lignin is 40 – 50 ºC. Above 60 ºC, these microorganisms cannot grow and lignin degradation becomes slow (Hassen *et al.*, 2001). After the thermophilic phase, corresponding to a peak of degradation of fresh organic matter, the microbial activity decreases, as the temperature also drops. This is called the cooling phase. The compost maturation phase begins when the compost temperature falls to the ambient air. This decrease initiates the beginning of depletion of organic matter; during this phase, the C:N ratio in the different windrows tend to stabilize. More specifically, mesophilic microorganisms colonize compost and continue to degrade complex organic compounds such as lignin. This last phase is important because humus-like substances are produced to form mature compost (Cooperband, 2000). Mineralization and humification occur simultaneously during composting and are the main processes of degradation of the fresh organic matter.

2.3.3.2 Compost maturity tests

For compost to be used as soil amendment, its high stability or maturity is desirable (Kuo *et al.*, 2004). A number of methods to test compost stability and maturity have been proposed over the last two decades as listed in Table 2.1.

Table 2.1. Methods for predicting compost stability/maturity (Kuo *et al.*, 2004)

Methods	**Parameter**
Physical analyses	Temperature, color
Chemical analyses	Nitrate - N, ammonium - N, water-soluble C, C:N ratio, cation exchange capacity, humic and fulvic acid
Microbiological assays	Respiration (CO_2 evolution; O_2 consumption)
Plant assays	Cress germination test in water extract, rye grass growth in compost containing mixtures
Spectroscopy analyses	Solid state CPMAS ^{13}C-NMR, infrared-FTIR

As heat is released during microbial degradation of organic matter, temperature of composting mix is a good indicator of its stability. The Dewar Test (Brinton, 2000) is often employed for the determination of compost self-heating. When the increase above ambient temperature from self-heating is less than 10 ^oC, the compost is classified as completely stable (Table 2.2). As self-heating intensifies by the further rise in temperature above ambient, the compost becomes increasingly immature. Being simple and easy to use, Dewar Test is used by many composting facilities around the world.

Table 2.2. Dewar self-heating test and CO_2 loss for determining compost maturity (Kuo *et al.*, 2004)

Heat rise over ambient (^oC)	**Rating**	**Description of stability**
0 to 10	V	Completely stable, can be stored
10 to 20	IV	Maturing compost, can be stored
20 to 30	III	Material still composting, do not store
30 to 40	II	Immature, active composting
40 to 50	I	Fresh, very active composting

As composting proceeds, a greater C than N loss results in the reduction of C:N ratio (Eghball *et al.*, 1997). When C:N ratio reaches below 25:1, the compost is generally considered to be mature. Despite a close relationship between the change in C:N ratio and the change in cations exchangeable capacity (CEC) or in the concentration of humic acids (Inbar *et al.*, 1989), C:N ratio alone is not a good index of maturity of composts made from a diversity of waste streams and bulking agents. The representation of compost maturity by C:N ratio can be misleading particularly when the compost contains elevated levels of ammonium - N. This form of N is part of organic N if Kjeldahl N is used to reflect organic N. While C:N ratio is an important characteristic of organic residue that determines N mineralization and N mineralization potential (Kuo *et al.*, 1997; Kuo *et al.*, 2004), it has not been consistently a good indicator of compost N mineralization potential.

2.3.3.3 Nitrogen mineralization dynamics of compost

Composting tends to reduce N mineralization rate of organic wastes (manures, crop residues, etc.), but mineralization rates of composts vary nearly as widely as those for non-composted manures (Hartz *et al.*, 2000). Working on two types of compost, Fening *et al.* (2010b) reported that composting improves nutrients content of cattle manure and its fertilizer value. They demonstrated that 2:1 compost (plants materials:manure) had higher decomposition rate than 1:1 compost with half-life of 35 and 23 days for the 2:1 and 1:1 compost types, respectively. Decomposition of organic resources adds nutrients to soil. Indeed, several workers have demonstrated that the single exponential model describes reasonably well the decomposition rate of plant residues (Vanlauwe *et al.*, 1997; Bayala *et al.*, 2005; Teklay *et al.*, 2007). The nitrogen mineralization from some composts takes place slowly due to high C:N ratios of amendments (Binh *et al.*, 2015).

2.3.3.4 Effect of compost on soil microbiological properties

Microbial biomass is one of the essential living components of all terrestrial ecosystems because it regulates various critical processes such as the decomposition of organic material, its transformation and the nutrient cycling of carbon and nitrogen of the soil (Mabuhay *et al.*, 2003; Kara and Bolat, 2008; Xu *et al.*, 2008). Soil microbial biomass represents only a small fraction of the total amount of soil C and N and has a relatively rapid turnover (Wang *et al.*, 2007). The addition of good quality composts may increase global microbial biomass (Albiach *et al.*, 2000; Perucci *et al.*, 2000; Debosz *et al.*, 2002). Consequently, it is believed that compost application increases the environmental carrying capacity of N through microbial biomass and decreases the nitrate - N leaching in agricultural land. If nitrate - N leaching derived from chemical fertilizer can be decreased by increasing microbial biomass N (immobilization), then improvement of the environment and N uptake by plants can be expected (Herai *et al.*, 2006). Soil microbial biomass is also a very important reservoir of phosphorus in the soil (Oberson *et al.*, 1997). According to Morel *et al.* (1996), the microbial population plays a central role in P cycling and availability. The distribution of microbial biomass C values is related to the moisture content in the soil (Cañizales-Paredes *et al.*, 2012). The greatest values are found in soil with the greatest moisture retention, which propagates the growth of microbial population because as moisture conditions improve, a positive effect is observed on the mineralization of organic carbon and its utilization in cellular synthesis (Raich and Schlesinger, 1992). Biomass N and C showed increases in the soil immediately after compost addition and for up to one month, while biomass P showed an increasing trend for 5 months as reported by Perucci (1990). Application of 2.5, 10, 20, and 40 Mg ha^{-1} manure sludge waste compost increased soil microbial biomass C when compared to a control (Bhattacharyya *et al.*, 2003).

In a long-term experiment, it was found that multiple additions of manure sludge waste compost at rates of 20 and 80 Mg ha^{-1} increased microbial biomass C, and this increase persisted 8 years after application (Garcıa-Gil *et al.*, 2000). Furthermore, Chowdhury *et al.* (2000) observed that manure compost with high easily decomposable C was more effective than sawdust and rice husk composts in enhancing soil microbial biomass C. However, other researchers consider soil microbial biomass to be a poor indicator of changes taken place in soil, since a number of factors, such as composition of the microbial population, frequency of addition of organic matter, quality of organic residues, soil moisture, and active microbial antagonist populations, may significantly influence microbial activity and nutrient turnover but not the microbial population mass in all cases (Binkley and Hart, 1989; Theng *et al.*, 1989; Mazzarino *et al.*, 1991; Bilkisu and Babatunde, 2015). Soils in semi-arid areas have a very low level of microbial biomass and low organic matter content (Garcıa-Gil *et al.*, 2000) because of low organic materials application. Bending *et al.* (2004) observed that the size of the microbial biomass can be considered as an index of soil fertility and indicator of soil quality, which depends primarily on rate of nutrient fluxes (Singh *et al.*, 2007).

2.4 Effect of organic and inorganic resources on soil properties

2.4.1 Soil organic matter

The benefits of increased soil organic matter content in terms of nutrient uptake by crops have been demonstrated by several experiments (Johnston, 1986; Oad *et al.*, 2004; Merwad and Abdel-Fattah, 2015). McConnell *et al.* (1993) reported that compost applied at rates varying from 18 to 146 t ha^{-1} produced 6 to 163 % increase in soil organic matter. The study of Zebarth *et al.* (1999) over three-year period showed increases in soil organic matter from 5 different organic sources including bio solids, food waste and composted pig manure. Eghball (2002) reported that 25 % applied manure C remained in the soil after four years period compared with 36 % applied compost C suggesting that compost may have greater benefits for C sequestration than manure. Addition of organic fertilizer improves soil quality

(Huang and Sun, 2006) and stimulate increase in organic carbon (Shibabaw and Melkamu, 2015). Gregorich *et al.* (2001) has also showed how the use of organic manures and compost more readily enhances the soil organic carbon pool than application of the same amount of inorganic fertilizer.

2.4.2 Soil pH

The effect of compost on soil pH is likely to depend both on the initial pH of the compost and the initial soil pH. There are reports in the literature of composts both increasing and lowering the pH of soils, and others where no effect was measured

(Zebarth *et al.*, 1999; Crecchio *et al.*, 2001). Working in acid soils, Mokolobate and Haynes (2002) found that additions of organic residues increased the pH of the soil in the order poultry manure > filter cake > household compost > grass residues when the residues were added at the same rate. Abdel-Rahman (2009) and Merwad and Abdel-Fattah (2015) demonstrated that soil pH increased from 6.7 to 7.5 and 8.15 by compost and manure application, respectively. The response was in direct relationship to the basic cations present in organic amendment applied.

2.4.3 Soil nitrogen

Incorporation of N rich of fresh plant material, manures or composts leads to rapid mineralization and a large rise in soil mineral N. Egelkraut *et al.* (2000) investigated the relationship between soil texture and mineralization of N from both composted and fresh organic materials, in both cases mineralization was greater in sandy than clay soils.

In the year of application, Cooperband *et al.* (2002) observed that nitrate - N released from composted poultry manure (composted for 1, 4 and 15 months) was 3 - 4 times lower than from raw poultry manure, and that available soil nitrate-N from composts was no greater than from an unfertilized control. It has been shown that soils which receive organic matter inputs (manure, compost) on a regular basis generally have greater N supplying ability than soils which receive only mineral amendments (Gunapala and Scow, 1998; Bouajila and Sanaa, 2011). Despite the role played by organic materials to limit soil fertility depletion, they cannot restore the N uptake by crops. However, for good soil fertility management it is necessary to add inorganic N source to soils.

2.4.4 Soil phosphorus

Organic resources will play limited role in replenishing soil P due to their low P content and their limited supply at farm level (Palm *et al.*, 1997b). Richardson *et al.* (2009) reported that organic materials and microorganisms may increase agricultural P by improving the availability of phosphorus already in the system. This is particularly important in P-fixing soils where a major proportion of soil P is unavailable in the short-term due to fixation. Soil P levels increased with continued application of composts (Sharpley *et al.*, 1997) and in soils already high in P, addition of composts carries with it a risk of P leaching. Baziramakenga *et al.* (2001) demonstrated that a composted mixture of paper sludge and poultry manure increased the extractable P in soils. Mixing rock phosphate with manure and compost is likely to be beneficial for phosphate availability in soil, since acids in the decaying organic matter will aid the dissolution of the rock. Phosphorus is the most limiting factor to crop production in the sandy soils in Niger, with available P in these soils being very low (less than 2 mg P kg^{-1}) (Adamou *et al.*, 2007). However, Manu *et al.* (1991) working on a fertility study earlier in Niger found that the amount of total P in these soils ranged from 25 to 340 mg kg^{-1} with a mean of 109 mg kg^{-1}. The low content of both total and available P parameters may be related to several factors including nature of parent materials, form in the soil and low level of organic matter. About 80 % of the soils in sub-Saharan Africa are short of this critical nutrient element and without the use of inorganic phosphorus, other inputs and technologies cannot be effective (Adamou *et al.*, 2007).

2.4.5 Soil potassium

In compost, K remains in water-soluble forms and thus does not need to be mineralized before becoming plant available. However, for the same reason it is at risk of leaching during the composting process and thus compost is often a poor sustainable source of K (Barker *et al.*, 1997). Composting of organic wastes does not appear to affect K availability but application may affect both soil K (Baziramakenga *et al.*, 2001) and plant K uptake (Chen *et al.*, 1996).

Compost made from grass and straw has been shown to contain approximately twice the K content of chicken manure (Eklind *et al.*, 1998). This type of material might therefore be beneficial in stockless organic systems. Despite the role played by organic materials to limit soil fertility depletion they cannot restore the K uptake by crops. However, for a good soil fertility management strategy it is necessary to add inorganic K source to the soil.

2.4.6 Other soil elements

One of the perceived benefits of the use of compost over mineral fertilizer is their ability to provide non-NPK nutrients. For example, Hue (1988) attributed increased crop yields from crop treated with sewage sludge compost rather than mineral fertilizer to Ca and Mg supply. Studying a range of nutrients, Warman and Cooper (2000) found that the effect of application of composted and non-composted poultry manure on soil nutrient levels was generally similar. However, Ca levels in the topsoil were significantly higher from the composted manure. Bationo and Mokwunye (1991) reported that in the Sudano - Sahelian zone, the effective cation exchange capacity (ECEC) is more related to organic matter than to clay, indicating that a decrease in organic matter will decrease the ECEC and subsequently the nutrient holding capacity of these soils.

2.4.7 Soil water holding capacity

Water holding capacity (WHC) of soils is controlled primarily by: (i) the number of pores and pore-size distribution of soils; and (ii) the specific surface area of soils.

Because of increased aggregation, total pore space is increased (Kladivko and Nelson, 1979). Furthermore, as a result of decreased bulk density, the pore-size distribution is altered and the relative number of small pores increases, especially for coarse textured soils (Volk and Ullery, 1993). The increased WHC at lower tensions such as those at field capacity is primarily the result of an increase in number of small pores. Sandy soils have much less surface area than clayey soils and, thus, retain much less water at higher tensions. However, with the addition of organic matter, the specific surface area increases resulting in increased WHC at higher tensions (Edwards *et al.*, 2000). Soil "holds" water available for crop use, retaining it against the pull of gravity. This is one of the most important physical facts for agriculture. Application of wastes, either for plant nutrient supply or for disposal purposes, increases the C content of the soil. An increase in C content of the soil increases WHC and decreases bulk density (Weil and Kroontje, 1979).

Increasing the WHC of soils provides more available water to plants and can also help in resistance to drought. In a non-aggregated soil, any effects on water retention are likely to be due to the properties of the compost material itself. However, in a more structured soil changes in both aggregation and pore size and continuity may affect the water holding capacity (Hernando *et al.*, 1989; Giusquiani *et al.*, 1995;
Chen *et al.*, 1996; Baziramakenga *et al.*, 2001) and have all found increased soil water holding capacity after application of urban wastes. Edwards *et al.* (2000) found that compost made from a mixture of potatoes, sawdust and manure increased soil moisture over that of the untreated soil. Soil organic matter is important for sustainable land use management resulting in retention and storage of nutrients, and increasing WHC. Furthermore, the application of organic materials can improve soil WHC in semi-arid Niger and enhance crop productivity.

2.5 Importance of combined application of organic and mineral fertilizers Vogel *et al.* (1994) reported that up to 54 % of fertilizer N applied to a maize field at an agricultural site in Zimbabwe was leached out of the plough layer (0 - 500 mm) when heavy rains were preceded by N fertilizer application. Kamukondiwa and Bergström (1994) reported N leaching losses of up to 39 kg N ha^{-1} $year^{-1}$ in summer (maize) and 18.6 kg N ha^{-1} $year^{-1}$ in winter (wheat under irrigation) on a deeply weathered sandy soil at Grassland Research Station, Zimbabwe, in a study that was carried out during a sequence of very dry years. This implies that N leaching potential will be higher in normal rainfall years. An accumulation of P in fertilized soil is consistent with other studies which show that the use efficiency of applied P (as superphosphate) by plants is only 10 - 20 % in the year of application and generally reaches a maximum of around 50 % over time due to residual value (Holford, 1997; Richardson *et al.*, 2009).

There are several ways in which agricultural practices are already conducted to optimize the uptake efficiency of P fertilizer such as strategic placement and banding of P fertilizer within the soil (Richardson *et al.*, 2009). The combination of organic material and soluble P fertilizer address the problem of limited accessibility to both plant materials and commercial fertilizer (Nziguheba, 2007). Conceptually, the combination of mineral fertilizer and organic material would be more advantageous than the sole application of organic or inorganic fertilizer. The quality of the organic material used and the proportions of nutrient applied from either source would determine the effect of the combination (Palm, 1995). An advantage of combined application of organic and inorganic P sources over organic materials alone is that it contributes to P replenishment from the inorganic P fertilizer (Nziguheba, 2007).

2.6 Effect of compost and mineral fertilizer on cereals/legumes productivity In the sub-humid zone of Burkina Faso, surface application of compost at 5 t ha^{-1} led to grain and straw yield increases of sorghum (*Sorghum bicolor* (L.) Moench) of 46 - 69 % and 16 - 20 %, respectively, above the control in the year of application (Ouédraogo *et al.*, 2001). Similarly, Dommergues and Ganry (1986) reported yield increases of 13 and 54 % above the control in soybean (*Glycine max* (L.) Merr.) and maize (*Zea mays* L.) grain, respectively, when applying 1.5 - 2 t ha^{-1} of compost.

In fact, yield responses to inorganic fertilizer and organic inputs are generally positive in Niger, where the responses can vary with the amount of rainfall (Ibrahim *et al.*, 2015). Split applications of N fertilizer can be adjusted during the season according to the degree of water stress (Gebremariam, 2015), and conservation of water can enhance the beneficial effects of fertilizer application (Mokwunye *et al.*, 1996; Sharma *et al.*, 2015).

There is a wealth of site-specific information about the short-term yield enhancing effects of P and N fertilizers and compost on cereals and legumes grown on severely nutrient deficient soils of Sub - Saharan West Africa (SSWA) (Buerkert *et al.*, 2001; Buerkert *et al.*, 2002; Muehlig-Versen *et al.*, 2003). Single superphosphate (SSP) applied annually at 13 kg ha^{-1} effectively removed P deficiency on most soil types tested throughout SSWA. Phosphorus-induced yield increases in cereals have been shown to substantially increase with N application. Despite site-specific variation in the relative importance of N and P, experimental evidence from Mali strongly suggests that the relative importance of N compared with P increases with rainfall from north to south across the Sudano - Sahelian zone and that at most sites (Schlecht *et al.*, 2006).

Significant cowpea responses to nitrogen applied as urea have been obtained in different agro ecological zones of the West African Semi-Arid Tropics (WASAT). Legumes such as cowpea have a high P requirement. P is reported to stimulate root and plant growth, initiate nodule formation, as well as influence the efficiency of the rhizobium-legume symbiosis. The application of P fertilizer can triple cowpea biomass production. In the Sahel, the recommended rate of nitrogen and phosphorus on millet is 30 kg ha^{-1} (Bationo and Ntare, 2000) and 13 kg ha^{-1} (Buerkert *et al.*, 2000), respectively, while the recommended rate of nitrogen and phosphorus on cowpea is 15 kg ha^{-1} (Dugje *et al.*, 2009) and 26 kg ha^{-1} (Amba *et al.*, 2011), respectively.

2.7 Economic benefit of combined use of organic and inorganic resources

Economic indicators are used to measure the productivity, profitability, and stability of farming activities (Zhen and Routray, 2003). Sydorovych and Wossink (2008) contented that a sustainable farming system should be able to maintain its productivity and profitability indefinitely by relying more on its own inputs and capital. Productivity is the efficiency of input on output. Productivity is measured from two standpoints: technical efficiency of resources, expressed in terms of physical amounts, and economic efficiency in terms of monetary value (Rasul, 1999). Zhen and Routray (2003) reported that yield per hectare is used to measure the productivity of land. Lynam and Herdt (1989) proposed Net Present Value (NPV) from cost - benefit analysis as an indicator of economic productivity. This indicator is estimated as the value of outputs divided by the value of inputs. Lynam and Herdt (1989) observed that a farming enterprise is productive and would not operate at an economic loss if NPV is greater than or equal to one. However, Tisdell (1996) challenged the responsiveness of this indicator to economic sustainability of a farming system as it did not reflect profit accrued. Tisdell (1996) therefore proposed a parallel indicator: the ratio of output value less input value and divided by the input value. This indicator must satisfy the condition that it will be equal to or greater than zero, otherwise it is meaningless. Value cost ratio (VCR) is another frequently used indicator of profitability. The VCR relates agronomic efficiency to the prices of inputs and outputs. A farming enterprise satisfies conditions for economic viability when the VCR is greater than one (Zhen and Routray, 2003). Most of the researchers used VCR for analyzing economic benefits and financial considerations. However, it was observed that sometimes VCR did not coincide with grain yield and net return (Khaliq *et al.*, 2006). In addition, the relative increase in income (RII) reported by Yinbo *et al.* (1997) can also be used for more appropriate economic analysis of different inputs.

2.8 Summary of literature review

The low soil organic matter and limited availability of plant nutrient are major bottlenecks to food production in West Africa. To remedy this agricultural constraint, the uses of inorganic and organic fertilizers have been proposed to increase soil and crop productivity. However, the application of inorganic fertilizer is not usually affordable to a large segment of African farmers and organic fertilizer may not be available due to other competitive uses. To minimize the effect of this threat, it is necessary to manage the capacity of soils in the region to support increasing crop production through using available low soil fertility management practices. This has opened a new wave of research in an attempt to find low-cost solutions to improve soil fertility and achieve the ultimate goal of food security. The combined use of available organic and modest quantity of mineral fertilizer could be a solution. Millet glume represents a potential source of organic material. In search for a solution to the poor fertility status of soils, farmers in Niger have already started using millet glume based-compost as soil amendment. However, studies geared towards enhancing the quality of MGB-compost and its contribution to soil and crop productivity are not available in Niger. For achieving the goal of food production improvement as expected by small holder farmers, it is necessary to explore the management of millet glume, in order to effectively manage and fully exploit the nutrient availability from this organic material. Furthermore, there is a need to understand how the application of MGB-compost in combination with mineral fertilizer influence soil nutrient availability and improve millet and cowpea productivity. It is also important that the proposed management interactions are of immediate economic benefit, the prime indicator which guides farmers‟ decision to adopt new technologies.

CHAPTER THREE

3.0 Materials and Methods

3.1 The survey area

The District of Aguié/region of Maradi is located in the semi - arid zone of Niger. It lies between latitude 13° 30′ 12″ N and longitude 7° 46′ 37″ E. The land area of the District is estimated as 3001 km^2 with a population of 246,160 (INS, 2013). The soils are sandy-loam to clay, making them ideal for the cultivation of most staple food crops. The District has unimodal rainfall (from July to September) with mean annual rainfall ranging from 300 mm in the North to 600 mm in the South. Mean monthly temperature ranges from 27 - 29 ºC. Temperature can reach 45 ºC and 10 ºC during the dry hot season and dry cold season, respectively (Harouna, 2002). Like most rural communities in Niger, majority of the people dwelling in the District are engaged in agriculture. It is estimated that about 87 % are employed in the agricultural sector. Millet, sorghum, cowpea and groundnut are the major crops cultivated in the District. Livestock rearing is undertaken by most households in the District. Key among these livestock is cattle, sheep and goat. The survey was conducted in Dan Saga village located between latitude 13° 31′ 83″ N and longitude 7° 44′ 10″ E.

3.2 Survey methodology

3.2.1 Sampling technique and questionnaire administration

Multistage sampling technique was used to sample respondents for the survey (Marshall, 1954). At the first stage, Aguié District was purposively sampled because of the indigenous knowledge of farmers about millet glume management. The second stage of the multistage sampling technique involved the sampling of Dan Saga village because of the awareness of farmers on millet glume-based compost (MGBcompost) preparation. Stratified sampling approach (Hansen *et al.*, 1953) was also used to capture farmers who knew the practice of MGB-compost (strata 1) and those who knew millet straw-based compost (MSB-compost) (strata 2). Hundred (100) households were interviewed using structured questionnaires. Thirty two (32) and 68 households preparing MGB-compost and MSB-compost, respectively constituted the target of the survey. Data was collected on farming households‟ demographics as well as on their agricultural activity. Specifically, detailed information on farmers‟ application of fertilizer (both organic and inorganic) was solicited. Information on art of composting organic materials was also collected. The survey was carried out in September 2013. A yield square was drawn in respondent farmer‟s field in order to get a relevant estimation of millet grain yield obtained by farmers from soil fertility management practice that they used. In addition to the survey instrument, personal field visitation and observations of millet threshing place were made. Interviews with key informants such as extension staff (NGO and local leaders) were also undertaken.

3.2.2 Data collection

Primary and secondary data (qualitative and quantitative) were used as the main sources of information. Primary data was collected through direct interviews by the use of structured questionnaire. Some secondary data from books, journals and articles were the sources of valuable inputs used in the preparation of the questionnaire for the study. Farmers‟ reluctance to say what they really thought in the presence of a stranger (Nolte *et al.*, 2007), caused difficulty in the authenticity of information collected. One enumerator from the area of survey was recruited and trained (for the technical nature of some questions) to help the researchers in the questionnaire administration and social collaboration of farmers.

3.3 Main materials used for composting

The main materials used for composting were millet glume, goat manure and wood ash.

3.3.1 Preparation of millet glume based-compost

The weights of millet glume and goat manure used were taken on air dry weight basis. The source of millet glume used was from five villages close to the experimental site (N‟Dounga/CERRA Research Station). The goat manure used for composting was obtained from the goat pen of the Faculty of Agronomy, University Abdou Mounouni of Niamey-Niger. Millet glume and goat manure were mixed in the ratio of 2:1, respectively. Wood ash (1/4 of all main material) and water were added. Fifteen days later, inoculum was prepared by mixing 20 kg fresh goat manure + 1.5 kg of urea. The mixture was incubated for three (3) days for the proliferation of decomposer populations involved in the composting process. The materials were then buried in a pit which measured 2 m × 2 m × 1 m and covered with polyethene sheet to minimize water loss.

Temperature was measured using an industrial thermometer graduated from 0 °C to 150 °C, by placing it in the compost pile for 5 minutes between 12:00 am and 1:00 pm. The temperature was taken daily for the first fourteen days and at 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 weeks after incubation. The ambient temperature was also measured by leaving the thermometer in the air for 5 minutes at each sampling time. The pile was watered with 100 L water once every ten (10) days to soften the substrate and thus facilitate degradation by decomposers. Several holes were made in the polyethene sheet using a wooden rod to allow for aeration/ventilation, hence oxygen needed by microorganisms for their growth during the process. In addition, the pile was turned after every ten days (during pile watering) with a shovel to ensure a homogenous mixture of the components of the pile, water and air. Watering of pile was stopped after sixty (60) days of composting. At 85 days of composting, MGBcompost (2:1) was then air-dried under a greenhouse condition and stored in bags until needed for the field experiment.

3.3.2 Decomposition and nutrient release pattern study

3.3.2.1 Nutrient release pattern of MGB-compost under field conditions

This study was carried out during the 2013 and 2014 cropping seasons at N‟dounga Research Station/CERRA-Kollo of Niger over a period of ten weeks. Litterbags (20 cm × 30 cm) were made from nylon mosquito nets (1.0 mm mesh size) as reported by Tetteh (2004). One hundred grammes of each material (millet glume, goat manure, MGB-compost) was put into the litterbags and buried in a randomized arrangement, replicated 4 times, at a depth of 10 cm in two parallel lines between bands of millet and cowpea.

Ten grammes each of millet glume, goat manure or MGB-compost was oven dried, ground and characterized before burying in the field. The filled litterbags were installed during millet sowing on 2 July, 2013 and 26 June, 2014. Each replication comprised 10 litterbags. Two litterbags from each replication were taken at 2, 4, 6, 8 and 10 weeks to monitor and determine the dry matter disappearance from the litterbags (Anderson and Ingram, 1993). At each sampling time, the remaining material in each litterbag was cleaned of sand manually with a soft brush. The fresh weight of the remaining organic material was recorded and dried at 65 ºC for 48 h to a constant weight.

Ten grammes of the organic material remaining in each of the two litterbags sampled from a given replication were mixed to make a sub-sample. The sub-samples were then ground to less than 1 - mm particle size and analysed for total nitrogen, phosphorus, potassium and organic carbon. The percentage dry weight, nutrient release and decomposition rates of millet glume, goat manure or MGB-compost at each sampling time was calculated as described by Gnankambary *et al.* (2008). The percentage dry weight of the remaining millet glume, goat manure or MGB-compost at time *t*, *Rt* (%), was calculated as follows:

$$Rt\ (\%) = 100\ x\ \frac{M_t}{M_0}$$

where:

M_t = dry weight of remaining millet glume or goat manure or MGB-compost at time t

M_0 = initial dry weight of millet glume or goat manure or MGB-compost in the litterbag.

The nutrient release from the decomposing organic materials was derived using the equation:

$$\text{Nutirent release}\ (\%) = 100\ x\ \frac{C_0 x M_0 - C_t x M_t}{C_0 x M_0}$$

where:

C_0 = initial concentration of the nutrient (N, P, K or C) in millet glume or goat manure or MGB-compost

C_t = concentration of the nutrient (N, P, K or C) in the decomposing millet glume or goat manure or MGB-compost at sampling time t

M_t = dry weight of remaining millet glume or goat manure or MGB-compost at time t

M_0 = initial dry weight of millet glume or goat manure or MGB-compost in the litterbag.

To describe the decomposition pattern and calculate decomposition rate constants (*k*), data for each organic material was modelled using a single exponential model as described by Olson (1963):

$M_t = M_0 e^{-kt}$ where:

M_t = dry weight of remaining millet glume or goat manure or MGB-compost at time t

M_0 = initial dry weight of millet glume or goat manure or MGB-compost in the litterbag.

Half-life (t_{50}) was calculated as described by Fening *et al.* (2010b):

$$t_{50} = \frac{-\ln(0.5)}{k}$$

where:

k = decomposition factor

3.3.2.2 Nutrient release pattern of MGB-compost under laboratory conditions

Nutrient release pattern of MGB-compost was determined using the aerobic leaching tube incubation procedure (Stanford and Smith, 1972). This method gives an estimate of potential nutrient released under optimal conditions of moisture and temperature. Glass tubes of 200 mm length with of 20 mm diameter were used. Ten grammes soil sample collected from the experimental site was put into leaching tubes of 2 cm diameter and 20 cm long and 100 mg of MGB-compost was added to the soil in the tube in three (3) replications and arranged in a completely randomized design. Control treatment (no amended soil) was also included in the set up. The experiment was conducted under laboratory conditions with maximum room temperature of 27 ºC. The samples in the tubes were leached at 0, 2, 4, 6, 8 and 10 weeks with 100 ml of 1.0 *M* KCl. Nitrate - N, ammonium - N, phosphorus, calcium and magnesium concentrations were then determined in the leachate. The nitrate - N and ammonium - N contents were determined by the salicylic acid and indophenol blue methods, respectively. Phosphorus was determined on a spectrophotometer by the blue ammonium molybdate method with ascorbic acid as a reducing agent. Calcium and magnesium in the leachate were determined by the EDTA titration method. A solution of 0.02 *M* EDTA was titrated with 10.0 ml aliquot of the leachate using cal red and Eriochrome Black T indicators for calcium and magnesium determination, respectively. After each leaching event, the tubes were subjected to mild suction to bring the water content of each tube to 60 - 70 % water holding capacity. The mineralization or immobilization was calculated using the difference between a nutrient in the amended soil and the control (no amended soil).

3.4 Field experiments

3.4.1 Description of the experimental site

Compost preparation was carried out at the *Centre Régional de Recherche Agronomique du Niger* (CERRA-Niamey/Station), Niger (longitude 2°07′55″ E and latitude 13°29′10″ N). The millet glume and goat manure (used for composting) and MGB-compost decomposition and nutrient release experiment were conducted during the cropping seasons at N‟dounga Research Station of *Centre Régional de Recherche Agronomique du Niger* (CERRA-Kollo/Station). N‟dounga is located on longitude 2°18′28″ East and latitude 13°25′00″ North, 30 km South-East of Niamey, Niger (Figure 3.1). The annual average rainfall over the last fourteen (14) years was 510 mm (CERRA-Kollo, 2014). The soils are classified as Psammentic Paleustalf (FAO, 1988) which is sandy, with moderate to low inherent soil fertility. The experiment on MGB-compost nutrient release pattern under laboratory conditions was conducted in 2013 and repeated in 2014 using leaching tubes at Soil Research Institute Laboratory, Kwadaso - Kumasi, Ghana (longitude 1º40′ E; and latitude 6º40′ N).

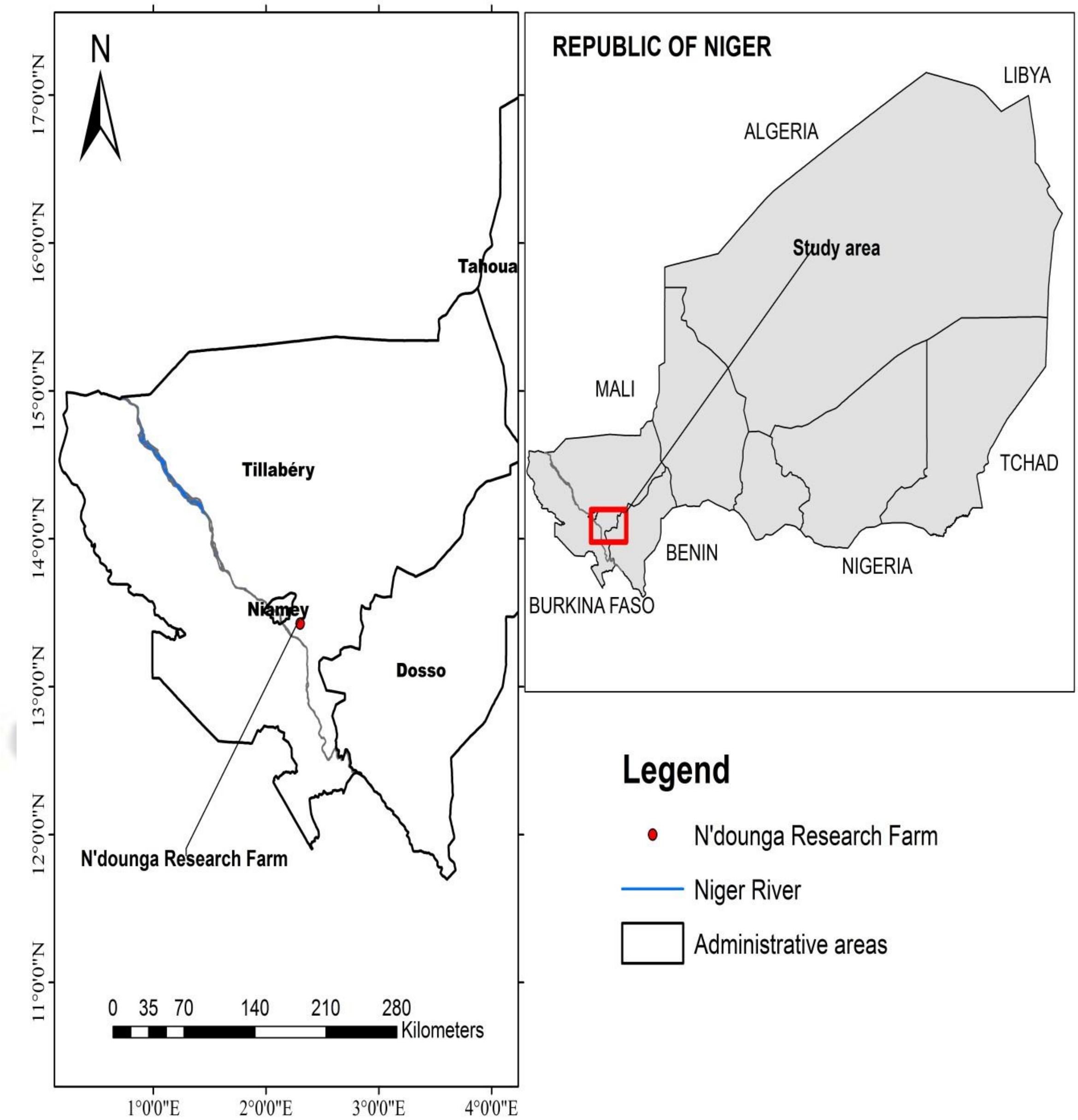


Figure 3.1. Location of experimental site (Source: SIG-Niger Database terrain, 2013)

3.4.2 Application of organic resources and inorganic fertilizer

Three levels of MGB-compost (C_0, C_{150} and C_{300} g hill^{-1}) were incorporated into the soil by hill application (Fatondji *et al.*, 2009) during seed sowing. The 150 g hill^{-1} and 300 g hill^{-1} of MGB-compost applied corresponded to 1.5 and 3 tons ha^{-1} on millet, respectively and also 4 and 8 tons ha^{-1} on cowpea, respectively.

Three levels of N (urea) combined with three levels of P (single superphosphate, SSP) (0 % $_{RR}$, 50 % $_{RR}$ and 100 % $_{RR}$ kg ha^{-1}; RR = recommended rate used), were applied to their corresponding plots. The 50 % and 100 % $_{RR}$ of urea applied on millet corresponded to 32.50 and 65 kg ha^{-1}, respectively. The 50 % and 100 % $_{RR}$ of SSP applied on millet corresponded to 99.50 and 199 kg ha^{-1}, respectively. However, the 50 % and 100 % $_{RR}$ of urea applied on cowpea corresponded to 16.25 and 32.50 kg ha^{-1}, respectively. The 50 % and 100 % $_{RR}$ of SSP applied on cowpea corresponded to 198.50 and 397 kg ha^{-1}, respectively. Nitrogen fertilizer was applied annually in two equal split applications at millet tillering and flowering and in one application on cowpea after seedlings thinning. Phosphorus fertilizer was applied once (at millet and cowpea sowing, onset of 2013 cropping season) throughout the two (2) years of the study (FAO, 2005).

3.4.3 Planting materials used

The planting materials that were used were: an improved cowpea variety (IT98K2058) developed at the International Institute for Tropical Agriculture (IITA) and a locally improved millet variety *(Haini Kiré Précose, HKP)*. The early maturing, dual purpose characteristic and farmer accessibility of the variety were the main reasons for selecting this variety. The millet variety HKP was selected for the study because of its grain yield productivity, stability and high adaptability of the variety in most rural areas of Niger (CNEV, 2012).

3.4.4 Treatment combinations

Millet was strip-cropped with cowpea using 5:5 millet/cowpea row proportions. The treatments used included 3 rates of MGB-compost (C_0, C_{150} and C_{300} g hill^{-1}) and 3 rates of N and P fertilizers (0 % $_{RR}$, 50 % $_{RR}$ and 100 % $_{RR}$ kg ha^{-1}) laid out in factorial design arranged in randomized complete block design with four (4) replications. The nine (9) treatment combinations were as follows:

T_1 = MGB-compost at 0.0 g hill^{-1} + 0 % N and P_{RR} (Control)

T_2 = MGB-compost at 0.0 g hill^{-1} + 50 % N and P_{RR}

T_3 = MGB-compost at 0.0 g hill^{-1} + 100 % N and P_{RR}

T_4 = MGB-compost at 150 g hill^{-1} + 0 % N and P_{RR}

T_5 = MGB-compost at 150 g hill^{-1} + 50 % N and P_{RR}

T_6 = MGB-compost at 150 g hill^{-1} + 100 % N and P_{RR}

T_7 = MGB-compost at 300 g hill^{-1} + 0 % N and P_{RR}

T_8 = MGB-compost at 300 g hill^{-1} + 50 % N and P_{RR} T_9

= MGB-compost at 300 g hil^{-1} + 100 % N and P_{RR}

Each plot size measured 9 m × 6 m. Millet planting density was 1 m × 1 m and that of cowpea was 0.75 × 0.50 m. Millet seeds were sown first after which cowpea seeds were sown two (2) weeks later. Seedlings were thinned to 2 plants per hill three (3) weeks after planting. Three weeding events were undertaken. Cowpea pest control (3 times, started from flowering) was also undertaken by using *Deltacal* pesticide. Harvesting was done at physiological maturity for both crops. Harvesting was done from 10 to 25 September in 2013 and 01 to 15 September 2014 on cowpea and on 25 October in 2013 and 15 October 2014 on millet. Grain yield and dry matter were harvested from the 3 central rows (3 m × 5 m for millet and 2.25 m × 5.5 m for cowpea) of each plot. The samples were sun-dried for one week and the panicles and pods were manually-threshed. The millet and cowpea grain and biomass were weighed and expressed in kg ha^{-1}.

3.5 Laboratory analyses

3.5.1 Soil sampling

3.5.1.1 Initial characterization of soil

To assess the nutrient status of the soil before cropping, soil samples were randomly taken at a depth of 0 - 15 cm from each plot. One part of fresh soil samples was stored in a refrigerator for microbial biomass nitrogen, phosphorus and carbon determination while the other part was subjected to texture and chemical analysis after air - drying and sieving through a 2 - mm sieve.

3.5.1.2 Soil sampling at harvest

From each plot, six plants (millet and cowpea) were randomly selected. Soil samples were taken from the base of each plant at a depth of 0 - 15 cm (Moore *et al.*, 2000) using an auger. The soil samples were thoroughly mixed and sub - sampled to obtain representative composite samples for each plot. Part of fresh soil sample was stored in a refrigerator for microbial biomass nitrogen, phosphorus and carbon determination. The remaining sample was air - dried and passed through a 2 - mm mesh sieve and analyzed for texture, pH (H_2O), organic carbon (OC), total nitrogen (N), available phosphorus (Bray P) and exchangeable bases (calcium, magnesium, potassium and sodium).

3.5.2 Soil chemical analyses

The following soil chemical properties were determined:

3.5.2.1 Determination of soil pH

The pH of the soil was determined using a Suntex pH (mV) meter (model 701) at soil:water ratio of 1:2.5 as described by McLean (1982). A 10 g dry soil sample was ground to pass through 2 - mm mesh size and weighed into a 50 ml beaker. To this, 25 ml distilled water was added and the suspension was stirred continuously for 15 minutes and allowed to stand for 30 minutes. After calibrating the pH meter with buffer solutions of pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

3.5.2.2 Determination of soil organic carbon

Organic carbon was determined by the modified Walkley - Black wet oxidation method (Page *et al.*, 1982). Two grammes of soil sample were weighed into 500 ml Erlenmeyer flask. A blank was also included. Ten ml of 0.1667 M $K_2Cr_2O_7$ solution was added to the soil and the blank flasks. To this, 20 ml of concentrated sulphuric acid (H_2SO_4) was added and the mixture allowed to stand for 30 minutes on an asbestos sheet. Distilled water (200 ml) and 10 ml of concentrated orthophosphoric acid were added and the excess dichromate ions $Cr_2O_7^{2-}$ in the mixture were backtitrated with 1.0 *M* ferrous sulphate solution using diphenylamine as indicator.

Calculation:

$$\%\ \text{Organic C} = \frac{M \times 0.39 \times (V_1 - V_2)}{W}$$

where:

M = Molarity of ferrous sulphate solution

V_1 = ml ferrous sulphate solution required for blank titration

V_2 = ml ferrous sulphate solution required for sample titration

W = Weight of air-dry sample in gramme

0.39 = 3 x 0.001 x 100 % x 1.3 (3 = equivalent weight of C)

1.3 = a compensation factor for incomplete combustion of the organic matter.

3.5.2.3 Determination of soil total nitrogen

This was determined by the semi micro Kjeldahl digestion and distillation procedure as described by Motsara and Roy (2008). One gramme soil sample was weighed into a Kjeldahl digestion flask. To this, 5 ml of distilled water was added. After 30 minutes, concentrated sulphuric acid (10 ml) and selenium catalyst mixture were added and mixed carefully. The sample was then digested for three (3) hours until a clear blue digest was obtained. The digest was diluted with 20 ml distilled water and mixed well until no more sediment dissolved. This was then allowed to cool. The volume of the solution was made to 100 ml with distilled water in a 100 ml volumetric flask and mixed thoroughly. A 25 ml aliquot of the solution was transferred to the distillation chamber and 20 ml of 40 % NaOH solution added followed by distillation for 10 minutes. The distillate was collected in 2.0 % boric acid and titrated with 0.02 *N* HCl using bromocresol green as indicator. A blank distillation and titration were also carried out to take care of the traces of nitrogen in the reagents as well as the water used.

Calculation:

% N in the sample was calculated as:

$$\%\ \text{total N} = \frac{(V_2 - V_1) \times N \times 0.014 \times 100}{W}$$

where:

V_1 = ml H_2SO_4 used in blank titration

V_2 = ml H_2SO_4 used in sample titration

N = Normality of H_2SO_4 used in titration

W = Weight of air-dry soil sample

3.5.2.4 Determination of soil available phosphorus

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

A 5 g soil sample was weighed into a shaking bottle (50 ml) and 30 ml of Bray‟s No.1 extracting solution added. The mixture was shaken for 5 minutes on a reciprocating shaker and filtered through a Whatman No. 42 filter paper. An aliquot of 5 ml of the blank, the extract and 10 ml of the colouring reagent (ammonium molybdate and

tartarate solution) were pipetted into a test tube and uniformly mixed. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21D spectrophotometer
(England, UK) at a wavelength of 660 nm at medium sensitivity.

Calculation:

$$\text{Available P mg kg}^{-1}\text{ soil} = PE \times \frac{TV}{W} \times \frac{FV}{AV}$$

where:

PE = Concentration of P (mg kg^{-1}) in the extraction

TV = Total volume

W = Weight of soil

FV = Final volume

AV = Aliquot volume mg kg^{-1} soil

3.5.2.5 Determination of soil exchangeable bases

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 *M* ammonium acetate (NH_4OA_c) extract, at pH = 7.0 as described by Black (1965).

3.5.2.5.1 Determination of soil exchangeable calcium

For the determination of calcium, a 10 ml portion of the extract was transferred into an Erlenmeyer flask. To this, 10 ml of potassium hydroxide solution was added followed by addition of 1 ml of triethanolamine. Few drops of potassium cyanide solution and few crystals of cal-red indicator were then added. The mixture was titrated with 0.02 *M* EDTA (ethylene diamine tetra acetic acid) solution from a red to a blue end point. The titer value for calcium was then recorded.

3.5.2.5.2 Determination of soil exchangeable calcium and magnesium

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

Calculation:

Ca + Mg or Ca cmol$_{(+)}$/kg soil

______________0.02 V x Wx 1000 where:

V = ml of 0.02 *M* EDTA

0.02 = concentration of EDTA

W = Weight in grammes of soil extracted

3.5.2.5.3 Determination of soil exchangeable magnesium

This was calculated by subtracting the value obtained for calcium alone from the calcium plus magnesium value.

3.5.2.5.4 Determination of soil exchangeable potassium and sodium

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

Calculations:

$$\text{Exchangeable K or Na } (\text{cmol}_{(+)}/\text{kg}) \text{ soil} = \frac{\text{Graph reading} \times 100}{39.1 \text{ or } 23 \times W \times 10}$$

where:

W = dried soil sample in grammes

39 = molar mass of potassium
23 = molar mass of sodium

3.5.2.6 Determination of soil exchangeable acidity

Exchangeable acidity consists of aluminium (Al) and hydrogen (H). Five grammes of soil sample was put into a shaking bottle and 100 ml of 1.0 *M* KCl solution added. The mixture was shaken for one hour and then filtered. Fifty millilitre portion of the filtrate was transferred into an Erlenmeyer flask and 2 - 3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.05 *M* NaOH until the colour just turned permanently pink. The amount of base used was equivalent to total acidity (Al + H). A few drops of 0.05*M* HCl were added to the same mixture to bring the solution back to colorless and 10 ml of 1.0 *M* sodium fluoride (NaF) solution added. The solution was then further titrated with 0.05 *M* HCl until the colour disappeared.

Calculation:

Exchangeable Al H cmol $_{(+)}$/kg soil ______ 0.05

V xW x 200 where:

0.05 = Molarity of NaOH or HCl used for titration V

= ml NaOH or HCl used for titration

W = Weight of air - dried soil sample in grammes

3.5.2.7 Calculation of soil effective cation exchange capacity (ECEC)

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

3.5.3 Determination of soil microbial biomass

3.5.3.1 Soil microbial biomass nitrogen

The fumigation - extraction method of Jenkinson and Ladd (1981) was used to determine microbial biomass N. Fresh moist soil samples (15 g) were put in 50 ml beakers and placed in a dessicator containing 30 ml alcohol-free chloroform in a beaker. The dessicator was then covered and kept for 72 hours at room temperature. Determination of biomass N was carried out immediately after fumigation by extracting the soil samples with 0.5 *M* K_2SO_4. Similarly, the non-fumigated subsamples were also extracted from its dessicator. The extract was analyzed for total N using the Kjeldahl digestion procedure. Biomass N was determined as follow.

Calculation:

Microbial biomass N = (Extracted N_{t1} – Extracted N_{t0})/k_N (Brookes *et al.*, 1985). where:

N_{t1} = Extracted N in fumigated sample N_{t0} =

Extracted N in non - fumigated sample k_N-factor of

0.54 was used for biomass N calculation

3.5.3.2 Soil microbial biomass phosphorus

For extractable microbial P, fresh moist sub-sample was shaken with Bray No. 1 solution (HCl:NH_4F mixture) for 5 minutes and then filtered through a Whatman No. 42 paper using Bray - 1 method. The extracted microbial P was then determined by the ammonium molybdate - ascorbic acid method. Microbial biomass P was determined as follow.

Calculation:

Microbial biomass P = (Extracted P_{t1} – Extracted P_{t0})/k_P where:

P = Extracted P in fumigated sample $_{t1}$

P = Extracted P in non - fumigated sample $_{t0}$

k_P-factor of 0.40 was used for biomass P calculation

3.5.3.3 Soil microbial biomass carbon

The amount of microbial carbon extracted in the 0.5 *M* K_2SO_4 solution was determined after an aliquot of the extracted carbon had been evaporated to dryness. The dichromate oxidation method was used for the determination of microbial carbon biomass (Vance *et al.*, 1987).

Calculation:

Microbial biomass C = (Extracted C_{t1} – Extracted C_{t0})/k_C where:

C = Extracted C in fumigated sample $_{t1}$

C = Extracted C in non - fumigated sample $_{t0}$

k_c-factor of 0.45 was used for biomass C calculation

3.5.4 Soil microbial quotient

The microbial quotient (Cmic/ Corg) was calculated as ratios of microbial biomass carbon (Cmic) to soil organic carbon (Anderson and Domsch, 1989).

3.5.4 Determination of selected soil physical parameters

3.5.4.1 Particle size analysis

The hydrometer method (Bouyoucos, 1962) was used for the determination of particle size distribution. A 51 g of air-dried soil sample was weighed into a „milkshake‟ mix cup. To this, 50 ml of 10 % sodium hexametaphosphate along with 100 ml distilled water were added. The mixture was shaken for 15 minutes after which the suspension was transferred from the cup into a 1000 ml measuring cylinder. With a hydrometer in the suspension, distilled water was added to reach the 1000 ml mark. The mixture was plunged several times until all soil was in suspension. The cylinder was placed on a flat surface and allowed to stand over a period of time. The first hydrometer and temperature readings were taken at 40 seconds. After the first reading, the suspension was allowed to stand for 3 hours and the second hydrometer and temperature readings were taken. The first reading represented the percentage of sand

and the second reading, the percentage of clay. The percentage of silt was determined as the difference of the first and second readings.

Calculations:

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

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

% Silt = 100 – (% sand + clay) where:

H_1 = Hydrometer reading at 40 seconds

T_1 = Temperature at 40 seconds

H_2 = Hydrometer reading at 3 hours
T_2 = Temperature at 3 hours

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

2.0 = Salt correction was added to hydrometer reading.

3.5.4.2 Determination of soil moisture content

Soil moisture content (θm) was monitored at millet tillering, flowering and physiological maturity stage (Fatondji, 2002) of 2014 cropping season. This was determined gravimetrically as described by Marshall and Holmes (1988). In this method, the loss in weight after oven-drying as a fraction of the fresh soil represents the moisture content. Two (2) separated soil samples were taken from each plot at about 5 cm depth from millet hill using Kopecky ring (Marshall and Holmes, 1988). The Kopecky ring was labelled and closed immediately after taking the sample using plastic lids and taken to the laboratory. The weight of each Kopecky ring with soil and the lid were recorded immediately. The Kopecky ring with soil was placed in the oven and dried at 105 ºC to a constant weight. The Kopecky ring was removed from the oven and placed in a desiccator and allowed to cool after which the Kopecky ring

+ oven-dried soil were weighed.

Calculation:

$$\text{Soil gravimetric moisture content } (\theta m) = 100 \; x \; \frac{W_1 - W_2}{W_2} \; \%$$

where:

W_1 = Weight of Kopecky ring + lid + fresh soil

W_2 = Weight of Kopecky ring + lid + oven-dried soil

3.5.4.3 Determination of bulk density

Bulk density (ℓ_b) was determined as the ratio between the oven-dried weight of soil and soil volume.

Calculation:

$$\text{Bulk density} = \frac{W_2}{V} \; (g \; cm^{-3})$$

where:

W_2 = Weight of Kopecky ring + lid + oven-dried soil

V = Volume of soil ($\pi r^2 h$)

3.5.4.4 Determination of volumetric moisture content

The volumetric moisture content (θv) was calculated by multiplying the moisture content by the bulk density (Anderson and Ingram, 1993) and is given as follows

— l

lb w 3 -3 θv θm m
m

where:

θm = Gravimetric moisture content (%)

lb = Bulk density lw= Density of water

= 1 000 kg m^{-3}

3.5.4.5 Porosity

The porosity (*f*) was computed from the equation:

lb
Porosity *f* 1 —
ls

where:

lb = Bulk density ls = Particle density, with a

value of 2.65 g cm^{-3}

3.5.5 Characterization of millet glume, goat manure and MGB-compost

Representative samples of millet glume, goat manure and MGB-compost were taken, dried at room temperature and ground to pass through a 1 mm sieve. Organic carbon, total nitrogen, phosphorus, potassium, magnesium and calcium of millet glume, goat manure and MGB-compost were determined (Motsara and Roy, 2008). Polyphenol and lignin contents of the millet glume, goat manure and MGB-compost materials were also determined (Anderson and Ingram, 1998).

3.5.5.1 Organic carbon determination

Organic carbon content of millet glume, goat manure and MGB-compost was determined using the dichromate-acid oxidation method. Ten millilitres (10 ml) each of concentrated sulphuric acid, 1.0 *N* potassium dichromate solution and 20 ml concentrated sulphuric acid were added to 0.05 g of sample in an Erlenmeyer flask. The solution was allowed to stand for 30 minutes after which 200 ml of distilled water was added followed by 10 ml orthophosphoric acid and 2 ml diphenylamine indicator. The solution was titrated against 0.5 *N* ferrous sulphate solution until the color changed to dark blue and then to a green end point. The titer value was recorded and the titer value for the blank solution also determined.

The organic carbon content of each sample was calculated from the equation:

$$\% \text{ Carbon} = \frac{N \times (a - b) \times 0.003 \times 100 \times 1.33}{W}$$

where:

N = Normality of ferrous sulphate a = ml ferrous suphate

solution required for sample titration b = ml ferrous

sulphate solution required for blank titration

W = Weight of oven - dried sample

0.003 = milli-equivalent weight of carbon

1.33 = compensation factor allowing for incomplete combustion

3.5.5.2 Total nitrogen determination

Total N was determined by the Kjeldahl method in which millet glume, goat manure and MGB-compost were each oxidized by sulphuric acid and hydrogen peroxide with selenium as catalyst. Twenty grammes of oven-dried sample was ground in a stainless steel mill and passed through a 1 - mm mesh sieve. A 0.5 g portion of the sample was digested in a 10 ml concentrated sulphuric acid and selenium mixture were added and mixed carefully. The resulting clear digest was transferred into a 100 ml volumetric flask and made to volume with distilled water. A 5 ml aliquot of the sample and a blank were pipetted into the Kjeldahl distillation apparatus separately and 10 ml of 40 % NaOH solution was added followed by distillation. The evolved ammonia gas was trapped in 15 ml of 2 % boric acid. The distillate was titrated with

0.1 *M* HCl with bromocresol green and methyl red indicator

Calculation:

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

where: a = ml HCl used for sample

titration b = ml HCl used for blank

titration

M = Molarity of HCl

$1.4 = 14 \times 0.001 \times 100\%$ (14 = atomic weight of N)

W = weight of sample

3.5.5.3 Dry ash digestion and analysis of plant tissues

One (1) gramme of plant sample was weighed into a clean ceramic crucible. The samples were arranged in a cool muffle furnace and temperature ramped to 500 ^{o}C over a period of 4 hours. This temperature was allowed to remain for an additional 1 hour after which the samples were allowed to cool down in the oven. Samples were then removed from the oven ensuring that the environment is free from breeze. Ashed samples were transferred first into already numbered 50 ml centrifuge tubes.

Crucibles were rinsed with 10 ml distilled water into centrifuge tubes. More rinsing of the crucible was done with 10 ml of aqua regia. The ash samples were shaken for 5 minutes for proper mixing on a mechanical reciprocating shaker. Samples were centrifuged for 5 minutes at 300 revolutions per minute (rpm) and then transferred into 100 ml volumetric flask and again made up to the 100 ml mark. The clear supernatant digest was decanted into clean reagent bottles for macro- and micronutrients determination following procedures described by Motsara and Roy (2008). The determination of elements in the ash sample prepared was done separately as described below.

3.5.5.3.1 Total phosphorus determination

Total P determination was by the spectrophotometric vanadium phosphomolybdate method. A 5 ml aliquot of the filtrate was taken into a 50 ml volumetric flask. Five milliliters of ammonium vanadate solution was then added and the volume was made up to 50 ml with distilled water and allowed to stand for 30 minutes for full colour development. A standard curve was developed concurrently with phosphorus concentrations ranging from 0, 5, 10, 15 to 20 mg P kg^{-1} organic material. The absorbance of the sample and standard solutions were read on a Jenway 6051 colorimeter (England, UK) at a wavelength of 430 nm. The absorbance values of the standard solutions were plotted against their respective concentrations to obtain a standard curve from which phosphorus concentrations of the samples were determined.

Calculation:

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

$$\text{P content g in 100 g plant sample, \% P} = \frac{C \;\; df \;\; 100\, x \;\; x}{1000\,000}$$

$$\text{P content g in 100 g plant sample, \% P} = \frac{C}{10}$$

where:

C = concentration of P (µg / ml) as read from the standard curve df

= dilution factor

3.5.5.3.2 Total potassium and sodium determination

Total potassium and sodium in the leachate were determined using a flame (analyzer) photometer. Standard solutions of potassium and sodium were prepared with concentrations of 0, 20, 40, 60, 80 and 100 mg L^{-1} of solution. The emission values which were read on the flame analyzer were plotted against their respective concentrations to obtain a standard curve.

Calculation:

K and Na content (μg) in 1.0 g of plant sample = C × df

$$\text{K, Na content (g in 100 g plant sample, \%)} = \frac{C \times df \times 100}{1000\,000}$$

where

C = concentration of K, Na (μg / ml) as read from the standard curve df

= dilution factor

3.5.5.3.3 Total calcium and magnesium determination

Total calcium and magnesium were determined using EDTA titration method. A 10 ml aliquot of the acid digest was pipetted into a 50 ml flask. One milliliter each of potassium cyanide and potassium ferrocyanide solutions was added to complex interfering cations like Cu and Fe. To determine calcium + magnesium concentration, the solution was titrated with 0.01 *M* EDTA solution in the presence of Eriochrome Black T indicator. For calcium determination, 5 ml of potassium hydroxide solution was added to raise the pH to 12 so as to precipitate magnesium, leaving calcium in solution. The solution was titrated with EDTA using cal-red as indicator.

Calculation:

Calcium in mg = Titre value of EDTA × 0.40

$$\% \text{ Ca} = \frac{\text{mg Calcium} \times 100}{\text{Sample weight}}$$

Magnesium in mg = Titre value of EDTA × 0.24

mg Mg × 100

% Mg ______________

Sample weight

3.5.5.4 Polyphenols determination

Polyphenol content was determined using the Folin - Denis method (Anderson and Ingram, 1998). One gramme each of dried, milled and sieved millet glume, goat manure and MGB-compost samples were weighed into 50 ml separate conical flasks. Ethanol (20 ml) was added to the sample and heated to 60 ^{o}C to extract the polyphenol. The extraction was repeated after the alcohol extract was decanted into another flask. After the third extraction, the volume of the extract was made up to 50 ml by adding ethanol. Standard solutions of tannic acid (with concentrations of 0, 20, 40, 80 and 100 mg tannic acid per liter) were prepared. The samples and tannic acid standards were subjected to color development.

Absorbance values of the standard and sample solutions were read on the spectrophotometer at a wavelength of 760 nm. A standard curve was obtained by plotting absorbance values against concentrations of the standard solutions and used to determine sample solution concentrations.

Calculation:

Polyphenol (mg kg^{-1}) = graph reading × sample dilution × aliquot dilution

3.5.5.5 Lignin determination

Lignin content was determined by acid detergent fiber method as described by Anderson and Ingram (1998). After the alcohol and dilute sulphuric acid extraction, 2 ml of 72 % sulphuric acid was added to the residue and shaken for 4 hours. The solution was transferred into a 100 ml Erlenmeyer flask with 40 ml distilled water, boiled for 2 hours and filtered. Sugar which represents cellulose was determined in the hydrolysate. The residue was washed with water, dried at 60 ^{o}C for 48 hours, weighed and then ashed in a muffle furnace at 550 ºC for 4 hours. The lignin content of the residue was considered as the loss in weight on ignition.

3.5.6 Harvest index of millet and cowpea

The harvest indices of millet and cowpea were calculated as described by Bange *et al.* (1998) and as follows:

$$\text{Harvest index HI} = 100 \times \frac{\text{Economic yield}}{\text{Biomass yield}}$$

3.5.7 Sustainability yield index and agronomic efficiency

The quantitative assessment of the sustainability yield index of agricultural practices was developed by Singh *et al.* (1990). Agronomic efficiency was developed by Novoa and Loomis (1981) and are mathematically expressed as follows:

$$\text{Sustainability yield index SYI} = \frac{Y_m - Sd}{Y_{max}}$$

and

$$\text{Agronomic efficiency AE} = \frac{Y - Y_0}{F_n}$$

where:

Y_m is the mean of grain yield

Sd is the standard deviation of the overall mean

Y_{max} is the maximum yield obtained under a set of the treatments applied

Y is the grain or biomass yield of a fertilized plot

Y_0 is the grain or biomass yield of the control plots

F_n is the amount of nitrogen or phosphorus applied

3.6 Economic analysis

An economic analysis study was done considering soil nutrients uptake from the treatments and the millet and cowpea yields resulting from the application of MGBcompost, N and P fertilizers over the two seasons. The cost of land preparation, planting and fertilizer application did not differ among treatments and were therefore ignored in the partial budgeting. The local market prices of the various inputs were used in the analysis. However, since the organic amendments (MGB-compost) had no direct market prices, they were costed in terms of labour incurred in compost preparation and transportation. The cost of mineral fertilizer was estimated on hectare basis. The benefits refer to the gains obtained by selling the harvested millet/cowpea grain in Niger. The prevailing prices of millet and cowpea grain were estimated based on the prices of the products at harvest period (Maman and Mason, 2013). Monetary values were converted to US Dollars (US$) at the exchange rate of 500 Fcfa = 1 US$ (Table 3.1).

Table 3.1. Parameters used to calculate the economic returns on investment of combined application of MGB-compost, N and P fertilizers in millet/cowpea production

Parameters	Franc CFA	US$
Cost of N P 100 % RR used on millet (Urea and SSP ha^{-1})	94875	189.75
Cost of N P 50 % RR used on millet (Urea and SSP ha^{-1})	47438	94.875
Cost of N P 100 % RR used on cowpea (Urea and SSP ha^{-1})	145661	291.322

Cost of N P 50 % RR used on cowpea (Urea and SSP ha^{-1})	72831	145.661
Cost of labor for 3 ton of MGB-compost ha^{-1}	137166	274.332
Cost of labor for 1.5 ton of MGB-compost ha^{-1}	68583	137.166
Price of millet grain ha^{-1}	300	0.6
Price of cowpea grain ha^{-1}	600	1.2

Exchange rate 1 US$ = 500 Fcfa

3.6.1 Quantification of added benefits

The added benefit from the combined application of MGB-compost, N and P fertilizers was calculated using the equation described by Vanlauwe *et al.* (2002) and as follows:

$$AB = Y_{comb} – Y\square_{N\,P} – Y_{con}\,\square – Y\square_{compost} – Y_{con}\,\square – Y_{con}$$

where:

AB = added benefits

Y_{comb} = mean grain yield from the combined application of MGB-compost, N and P fertilizers

$Y_{N\,P}$ = mean grain yield from the sole application of N and P fertilizers
Y_{con} = mean grain yield from the control

$Y_{compost}$ = mean grain yield from the sole application of MGB-compost

3.6.2 Returns on investment for the combined application of MGB-compost, N

and P fertilizers

The returns on investment for the combined application of MGB-compost, N and P fertilizers were assessed using the value cost ratio (VCR) and incremental income methods described by Khaliq *et al*. (2006) as follows:

Gross income (US$) = Grain yield obtained from treatment (kg) × cost of a kg of grain (US$)

Net income (US$) = Gross income (US$) – variable cost (US$)

Incremental income (US$) = Net income of treatment (US$) – Net income of control (US$)

$$\text{Value Cost Ratio VCR} = \frac{\text{Value of increased yield obtained}}{\text{variable cost}}$$

where:

Variable cost = cost of mineral fertilizer and labour involved in MGB-compost preparation and transportation

$$\text{Relative Increase in Income RII} = 100 \; x \left(\frac{\text{net income of treatment} - \text{income of control}}{\text{income of control}} \right)$$

3.7 Statistical analysis

Data collected from the survey were analyzed using Statistical Package for Social Sciences (SPSS 10.0) (Norris *et al.*, 2014). Frequency distribution tables were used to describe, organize and summarize the responses received on the demographic features of respondents" farmer, organic and inorganic fertilizer management and art of composting organic materials at household level. The t test analysis was performed to evaluate the effect of compost types applied by farmers on millet grain yield. The probability of 5 % was considered for treatment means separation in the t test analysis (Norris *et al.*, 2014).

Data of decomposing and nutrient release patterns of goat manure, millet glume and MGB-compost were subjected to excel software package for the calculation of the mean and standard error. Changes in soil chemical, moisture content and microbial properties as well as millet and cowpea grain and biomass yields were subjected to analysis of variance (ANOVA) using the GenStat (2007) statistical package by selecting general treatment structure (in randomized blocks). The combined years‟ analysis was used to take into account the year effect on some parameters of the study. Regression analyses (such as simple linear model) were also carried out. Correlation coefficient was used to establish the strengths of relationships between some of the estimated parameters. The separation of treatment means was done using Least Significance Difference (LSD) statistic at 5 % probability level (Payne and Committee, 2006).

CHAPTER FOUR

4.0 Results and Discussion

4.1 Survey on farmers' indigenous knowledge on millet glume management

4.1.1 Results

4.1.1.1 Demographic characteristic of respondents

Agriculture in the Dan Saga village is male dominated. More than 80 % of the respondents were males (Appendix 2). Most women are landless; hence their involvement in agriculture is greatly limited to assisting their male household heads. About two thirds of the respondents interviewed were aged between 30 and 60 years. The mean age was about forty (40) years. Numerous ethnic groups live in the survey area. The single largest was *Haoussa* who account for nearly 83 % of the respondents. Approximately 40 % of the farmers interviewed had no formal education, and could neither read nor write. Most of the respondents were married (84 %), with the rest being widowed, divorced or single. Agriculture was the dominant economic activity and farmers generally integrate crop production with livestock rearing. Averagely, farming households cultivated 2.5 hectares of land (Appendix 2). Due to the dominating arid conditions in the study area, main crops cultivated are: pearl millet, sorghum, cowpea and groundnut.

4.1.1.2 Soil fertility management practices

The results of the survey showed that 85 % of farmers used inorganic fertilizer (Appendix 3). The types of inorganic fertilizer used were NPK (15-15-15), diammonium phosphate (DAP), single super phosphate (SSP) and urea. More than 80 % of the respondents applied both organic and inorganic fertilizer. With respect to type of organic fertilizer applied, compost happened to be one major source. Farmers who used at least 70 % of millet straw as the base material were categorized as being users of millet straw-based compost (MSB-compost), while farmers who prepared compost with more than 70 % millet glume as the base material were classified as millet glume-based compost (MGB-compost). Other materials used in preparing compost were manure and ash (Appendix 3).

4.1.1.3 Method of compost preparation and maturity period

The methods of preparing compost influence its maturity. Farmers prepared compost using different methods. Whereas some farmers prepared compost in pits (the pit method), others heaped compost materials either outside on the bare ground or in mud structure. Some other farmers prepared composts and covered with polyethene sheet. Generally, 68.7 and 31.3 % of respondents who used millet glume as the base material for preparing compost used the pit and mud structure method, respectively (Table 4.1). The farmers who used MSB-compost used the four methods (pit, heap on bare ground (outside), heap in mud structure and heap covered with polyethene sheet) of compost preparation. Only about 6 % of these farmers prepared millet straw compost and covered it with polyethene sheet (Table 4.2). Even though covering the compost with polyethene sheet gives the best quality (thus without soil mixture), the additional financial burden of purchasing the polyethene sheet was a challenge.

Farmers were categorized based on whether they prepared compost using pit, heap in mud structure, heap on bare ground (outside), or used polyethene sheet to cover. About 34.3 % and 6.3 % of farmers, who used pit and heap in mud strucutre, respectively reported mature MGB-compost could be obtained in less than three months (Table 4.1). However, a relatively higher proportion (47 %) of farmers who prepared and applied MSB-compost in pit reported a 3-month maturity period (Table 4.2). Generally, most of the farmers interviewed used pit method which was mostly constructed around the homestead. To them, although this method is labour intensive, the maturity period is relatively shorter.

Table 4.1. Respondents" estimate of sufficient period for composting of millet glume

	Composting period					
	<3 months		3 months		6 months	
Methods	Freq.	%	Freq.	%	Freq.	%
Pit	11	34.3	10	31.3	1	3.1
Heap in mud structure	2	6.3	3	9	5	16
Heap on bare ground (outside)	-	-	-	-	-	-
Heap covered with polyethene sheet	-	-	-	-	-	-
Total	13	40.6	13	40.3	6	19.1

Source: Field survey, 2013; Freq. = frequency

Table 4.2. Respondents" estimate of sufficient period for composting of millet straw

	Composting period					
	<3 month		3 month		6 month	
Methods	Freq.	%	Freq.	%	Freq.	%
Pit	6	8.8	32	47	6	8.8
Heap in mud strucutre	3	4.4	1	1.5	7	10
Heap on bare ground (outside)	1	1.6	5	7.8	3	4.4
Heap covered with polyethene sheet	2	2.9	0	0	2	2.9
Total	12	17.7	38	56.3	18	26.0

Source: Field survey, 2013; Freq. = frequency

4.1.1.4 Effect of compost type on millet grain yield

The average millet grain yield (788 kg ha^{-1}) obtained by farmers interviewed who applied MGB-compost was significantly (P = 0.001) higher than that obtained by farmers who applied MSB-compost (556 kg ha^{-1}) (Table 4.3). This indicated that the source of materials used for composting significantly influenced millet grain yield.

Farmers (94 %) generally perceived compost as a good material for soil fertility and crop growth improvement, as a result of its positive influence on crop yield. About 78 % of farmers expressed their willingness to purchase MGB-compost as source of fertilizer. The mean application rate of MGB-compost and MSB-compost reported by respondent farmers were 697 and 620 kg ha^{-1}, respectively (Appendix 4).

Table 4.3. Effect of compost type on millet grain yield

Treatments	n	Millet grain yield (kg ha^{-1})	Mean difference	t	P-value
MGB-compost	32	788	231	8.8	0.001
MSB-compost	68	556			

Source: Field survey, 2013

4.1.2 Discussion

4.1.2.1 Demographic features of respondents

The results from the study indicated that mean field size in the survey area was 2.53 ha (Appendix 2). The field size was less than the values obtained by Hayashi *et al.* (2009) who reported that the average cultivated land area at local household level in Niger reaches 13.2 ha in the less densely populated areas and less than 5 ha in the densely populated area. The relatively higher male respondents (80 %) in the survey area could be attributed to males being predominantly owners of land and heads of the family in the area. Most of the respondents in survey area were between the ages of 30 and 60 years. This result is in convergence with that was found by Adebayo and Ajayi (2001) who reported an average age of 59 years for farmers involved in agriculture within the derived savanna and forest zones of Nigeria. The relatively high proportion (around 40 %) of farmers with non-formal education shows the low level of formal education of the farmers in Dan Saga village. This low level of education could be a constraint to dissemination of soil fertility management technologies. Kassie *et al.* (2012) reported that educational level is an important aspect of the adoption of technologies because educated farmers may be more appreciative of the benefits of new technology. Kipsat (2007) working on socioeconomics factors affecting soil conservation, demonstrated earlier that farmers with formal education had a better understanding of the threat of soil erosion on the environment. The study further showed that farmers of the survey area could distinguish between practices which improved their soil fertility and crops yield and those that did not. Generally, more than 80 % of respondents exhibited their willingness to purchase compost as fertilizer (Appendix 4).

4.1.2.2 Respondents' knowledge on compost and combined use of organic and inorganic fertilizer

The results showed that one main method (pit) was used by farmers for compost preparation. Muzira *et al.* (2003) working on composting water hyacinth reported that pit composting of water hyacinth reduced the amount of water needed during composting from 92 to 25 % and increased compost nitrogen concentration from 1.9 % to 3.4 % on dry weight basis. Most farmers in the survey area used compost prepared in heaps. With this technique, mature millet glume or straw-based compost could be obtained within 3 months. The method of aerobic composting reduce composting period of organic materials from 6 months to about 3 months. Farmers were well aware of the role of compost in improving soil fertility and sustaining yield (Appendix 4). Ouédraogo *et al.* (2001) and Abdel-Rahman (2009) reported that farmers adopt compost technology in Burkina Faso because of the low fertility status of their soils and yield decline in their fields.

The main sources of plant nutrients for growing crops identified during the survey were millet residues, manure, compost and chemical fertilizer (Appendix 3).

Inorganic fertilizer use can be one option of rapidly replenishing exhausted soils. Sanginga and Woomer (2009) reported that the use of inorganic fertilizer has been widely reported as a means of increasing crop production across West Africa. Some studies have, however, shown that the prolonged use of mineral fertilizer alone has resulted in decreasing crop yields due to soil acidification and loss of organic matter (Sedogo *et al.*, 1991; Zheng, 2010). Consequently, the recommendations now call for the use of inorganic fertilizer in combination with organic fertilizer. As reported by Jama *et al.* (1997), Thuita (2007) and Binh *et al.* (2015), significant increase of soil fertility and crop yields can be obtained by combined use of organic and modest quantity of mineral fertilizer. Many respondent farmers (81 %) in Dan Saga village were aware of the potential contribution of organic and inorganic fertilizers to crop production but still refrained from using them because of unavailability and high cost of organic and inorganic fertilizers, respectively. Indeed, farmers pointed out poverty as a major reason for not using inorganic fertilizer. In the Sahel, crop residues are totally removed from the fields, and used as building material or fodder for livestock (Manu *et al.*, 1994; Ouédraogo *et al.*, 2001). This study showed that millet glume is available and farmers use it for composting (Appendix 3). Therefore, millet glume can be an alternative organic material for soil fertility management in semi-arid zone of Niger.

This study also showed that in making compost, millet glume could be mixed with other organic materials such as manure (Appendix 3). Working in the semi - arid zone, Fernandez-Rivera *et al.* (1995) proposed the integration of animal husbandry and crop farming to ensure judicious management of organic resources for both animal production and soil management. Such integration has an additional benefit, which is the strengthening of the social relationships between farmers and livestock keepers. The main constraint mentioned by farmers about compost production is the labour requirements and this puts at risk the adoption of the practice by small households. To alleviate this type of constraint, Ouédraogo *et al.* (2001) proposed to strengthen and structure farmers‟ village groups for mutual support for the heavier tasks such as opening pits.

4.1.2.3 Effect of compost type applied on millet grain yield

The statistical analysis showed that the application of MGB-compost by farmers improved millet grain yield. The millet grain yield of 788 kg ha^{-1} reported by farmers as resulting from the application of MGB-compost was greater than the mean millet grain yield of 350 kg ha^{-1} reported by RGAC (2008) working under the farmers‟ circumstances in Niger. Maman and Mason (2013) reported that in Niger the mean grain yield over three years of sole application of poultry manure was 727 kg ha^{-1}. It is therefore evident that adopting the practice of composting millet glume could be a fair alternative of managing soil fertility towards improved crop yields in the semiarid zone of Niger.

4.2 Decomposition and nutrient release pattern of MGB-compost

4.2.1 Results

4.2.1.1 Chemical composition of MGB-compost

The chemical composition of millet glume and goat manure used for composting as well as the MGB-compost is presented in Table 4.4. The N content of the MGBcompost was 0.40 percent. Goat manure used for preparing MGB-compost had N content of 0.67 % while millet glume had 0.28 percent. The highest P content of 0.79 % was recorded for goat manure with the lowest (0.13 %) being that of millet glume. In general, the N and P contents of the organic amendments were in the order: goat manure > MGB-compost > millet glume. Calcium content ranged from a highest value of 2.60 % in MGB-compost to a lowest value of 0.70 % in millet glume. For magnesium, MGB-compost had the highest value of 0.82 % followed by goat manure (0.31 %) with millet glume having the lowest value of 0.25 percent. Polyphenol content with value of 2.84 % was higher in goat manure with MGBcompost having the lowest value of 1.65 percent. Millet glume had the highest value of 8.94 % of lignin content. High carbon and potassium contents of 39.25 and 0.9 % were recorded for goat manure and millet glume, respectively (Table 4.4). The calcium, magnesium, potassium and sodium contents of ash used in preparation of MGB-compost were 4.40 %, 2.80 %, 2.35 % and 1.33 %, respectively.

Millet glume had the highest carbon:nitrogen (C:N) ratio of 109.08. The lowest value of 28.58 was recorded for MGB-compost. The carbon:phosphorus (C:P) ratio was also highest (228.78) in millet glume with the lowest (38.43) value being recorded for MGB-compost. The polyphenol:nitrogen (PP:N) ratio was highest (7.33) in millet glume.

Millet glume had the highest lignin + polyphenol:nitrogen (L+PP:N) ratio of 41.20 and goat manure had the lowest value of 12.88. The same trend was observed for the lignin:nitrogen (L:N) ratio. The nitrogen:phosphorus (N:P) ratio of the organic amendments was highest (0.95) in millet glume followed by that of MGBcompost (Table 4.5).

Table 4.4. Chemical composition of millet glume, goat manure and MGB-compost

	Organic amendments		
Measured parameters	Millet glume	Goat manure	MGB-Compost
Total N (%)	0.28 (±0.03)	0.67 (±0.01)	0.40 (±0.01)
Total P (%)	0.13 (±0.01)	0.79 (±0.09)	0.31 (±0.02)
Total K (%)	0.9 (±0.01)	0.08 (±0.01)	0.08 (±0.03)
O.C (%)	29.92 (±3.46)	39.25 (±0.72)	11.16 (±0.77)
Total Ca (%)	0.70 (±0.25)	0.93 (±0.21)	2.60 (±0.28)
Total Mg (%)	0.25 (±0.09)	0.31 (±0.01)	0.82 (±0.08)
Polyphenol (%)	2.06 (±0.12)	2.84 (±0.18)	1.65 (±0.29)
Lignin (%)	8.94 (±0.70)	5.62 (±0.65)	5.95 (±0.50)

Values are the means of triplicate samples; values in brackets represent standard error

Table 4.5. Chemical ratio of millet glume, goat manure and MGB-compost

	Organic amendments		
Measured parameters	Millet glume	Goat manure	MGB-Compost
C:N	109.08 (±24.05)	56.85 (±2.32)	28.58 (±2.31)
C:P	228.78 (±44.23)	54.72 (±6.61)	38.43 (±3.85)
PP:N	7.33 (±1.10)	4.12 (±0.32)	4.20 (±0.73)
L+PP:N	41.20 (±2.24)	12.88 (±1.12)	19.48 (±1.33)
L:N	33.86 (±1.15)	8.76 (±1.14)	15.28 (±1.40)
N:P	0.95 (±0.01)	0.41 (±0.03)	0.64 (±0.05)

Values are the means of triplicate samples; values in brackets represent standard error

4.2.1.2 Temperature changes during composting

Temperature changes of MGB-compost measured over an 85 days period of composting is as shown in Figure 4.1. Temperature was monitored consecutively over the initial 14 days of composting. The two highest temperatures recorded during the composting period was 50 ºC at 28 and 35 days after composting. The lowest temperature of 36 ºC was also recorded in the MGB-composting after 85 days of maturation. Generally, temperatures for MGB-composting were relatively higher than the ambient temperatures till after 63 days of composting. The lowest and highest ambient temperatures recorded during the composting period were 35 and 45 ºC, respectively.

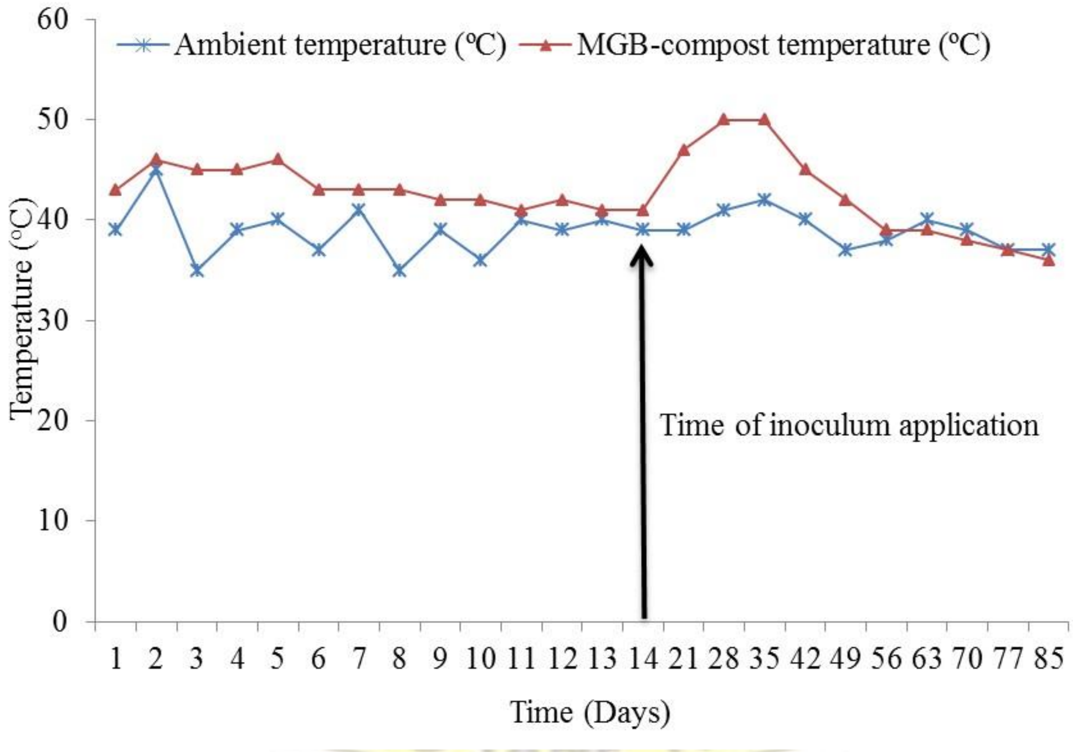


Figure 4.1. Changes in temperature during composting of millet glume

4.2.1.3 Decomposition and nutrient release pattern of MGB-compost under field conditions

4.2.1.3.1 Decomposition pattern of MGB-compost

The decomposition pattern of goat manure, millet glume and MGB-compost during the cropping season is presented in Figure 4.2. The weight of decomposing organic amendment remaining is expressed as percentage of the initial oven dried weight of the organic amendment. Within two weeks of decomposition study, MGB-compost decomposed faster than the goat manure and millet glume. By the 8th week, the MGB-compost had lost 71 % of its initial weight followed by goat manure with 36 %, and millet glume with 29 percent. The loss of weight at the end of the study period was in the order: MGB-compost (81 %) > goat manure (55 %) > millet glume (45 %). MGB-compost had the highest *k* value of 0.15 week^{-1} and millet glume, the lowest value of 0.06 week^{-1} (Table 4.6). This means that decomposition was fastest for MGB-compost and slowest for millet glume. The coefficient of determination (R^2) which indicates goodness of fit was very high (0.96 %) for MGB-compost. The half-life (t_{50}) values (i.e. the time for the organic amendment to lose half its initial weight) of the organic amendments were in the following order: MGB-compost (4.65 weeks) < goat manure (9.49 weeks) < millet glume (12.38 weeks) (Table 4.6).

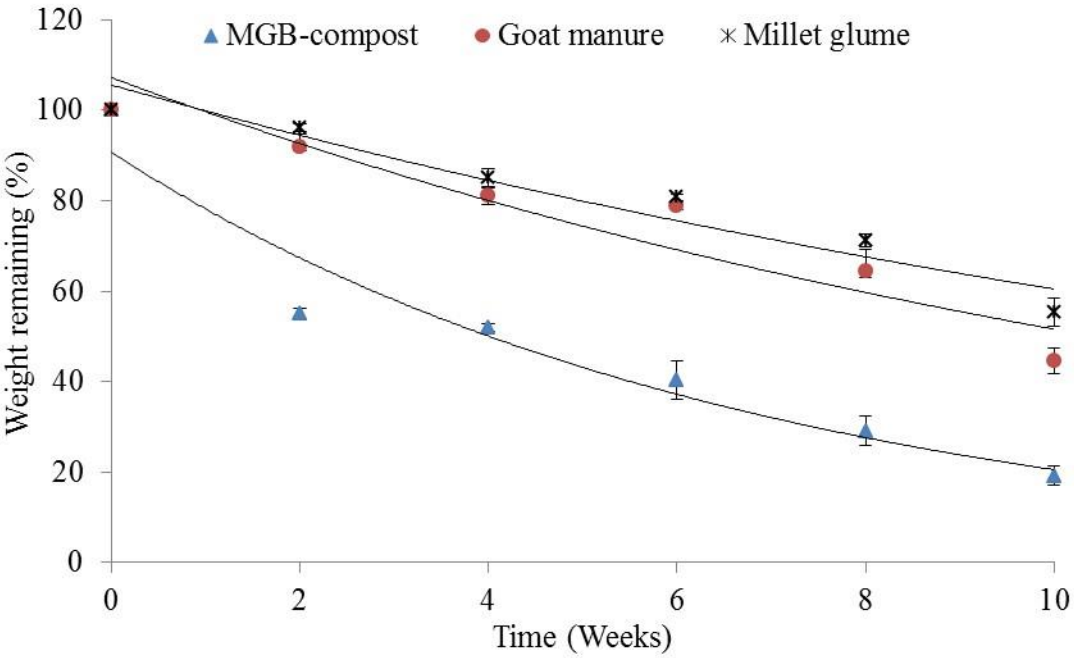


Figure 4.2. Weight remaining (%) of MGB-compost in the buried litterbags during cropping season. Bars denote standard error; trend lines represent the best fit.

Table 4.6. Decomposition rate constant (*k*), coefficient of determination (R^2) and half-life (t_{50}) of organic amendments

Organic amendments	Regression equation	*k* ($week^{-1}$)	R^2	Half-life (t_{50})
MGB-compost	$M_t = 90.76e^{-0.149t}$	0.15	0.96	4.65
Goat manure	$M_t = 107.27e^{-0.073t}$	0.07	0.89	9.49
Millet glume	$M_t = 105.62e^{-0.056t}$	0.06	0.92	12.38

M_t is the weight remaining (%) at the time t.

4.2.1.3.2 Nutrient release pattern of MGB-compost

4.2.1.3.2.1 Nitrogen

Figure 4.3 shows the N release pattern of the organic amendments during the cropping season. There was an initial rapid release of N from MGB-compost representing 59 %

of the total compared with the 29 % of the millet glume and 11 % of the goat manure. There was slower N release during the sixth week of incubation of the MGB-compost, which corresponded to millet elongation growth stage [6-8 weeks after sowing (WAS)]. At the end of the study period (millet flowering stage, > 9 WAS), MGB-compost released 87 % of its N while millet glume and goat manure released 78 % and 71 % of the N content, respectively.

4.2.1.3.2.2 Phosphorus

The release of P during the first two weeks of decomposition was most rapid for MGB-compost representing 52 % of the total N and slowest (20 %) was for millet glume (Figure 4.4). Almost all the organic amendments released more than 50 % of their initial P content by the sixth week of decomposition (millet elongation stage). At the end of study period (millet flowering stage, > 9 WAS), the amount of P released by goat manure was 92 % and 90 % by MGB-compost compared with 87 % for millet glume.

4.2.1.3.2.3 Potassium

Potassium release pattern from the organic amendments are shown in Figure 4.5. All organic amendments showed faster initial K release. At the end of study period (millet flowering stage, > 9 weeks), MGB-compost released 96 % of its initial K content followed by millet glume (80 %) and goat manure (75 %).

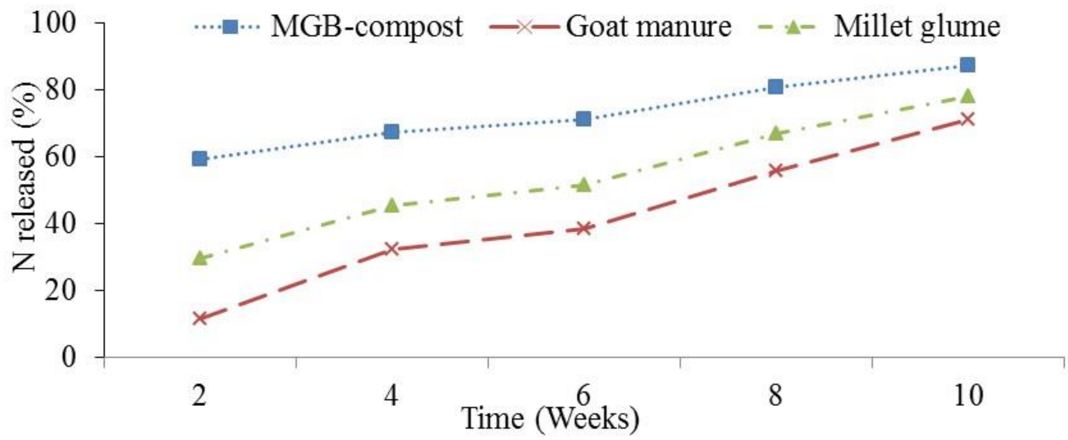


Figure 4.3. Nitrogen release pattern of MGB-compost, goat manure and millet glume under field conditions

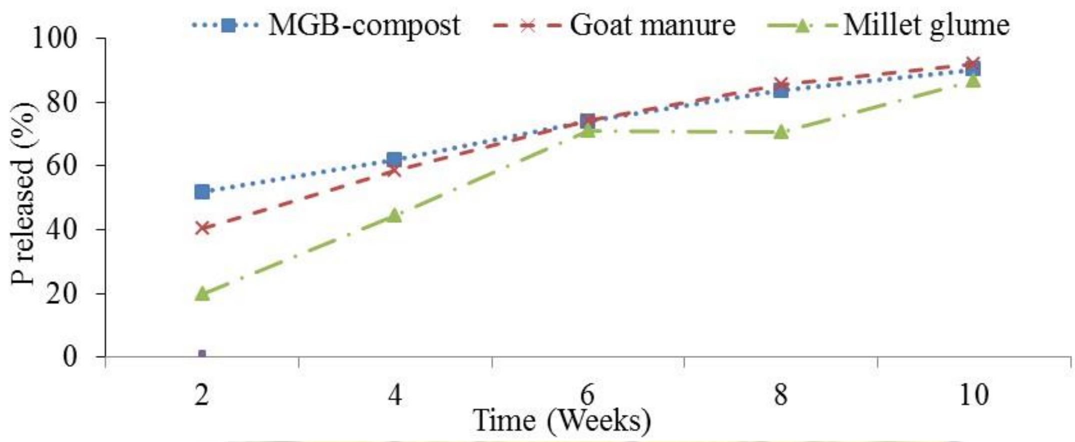


Figure 4.4. Phosphorus release pattern of MGB-compost, goat manure and millet glume under field conditions

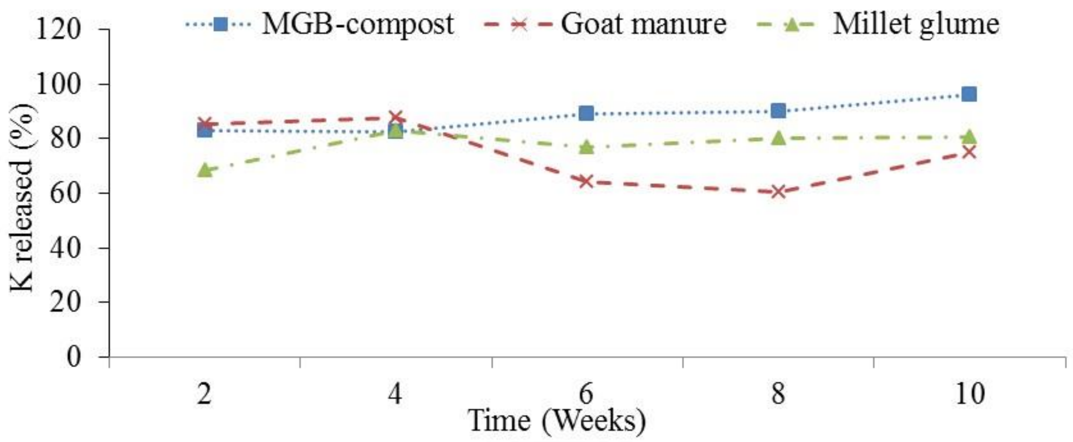


Figure 4.5. Potassium release pattern of MGB-compost, goat manure and millet glume under field conditions

4.2.1.3.2.4 Carbon

Figure 4.6 shows the carbon release pattern of the organic amendments. At the end of the sixth week, all organic amendments (except goat manure) had released more than 50 % of their carbon content. At the end of study (millet flowering stage, > 9 WAS), the amount of carbon released was 87 % for MGB-compost, 80 % for millet glume, and 74 % for goat manure.

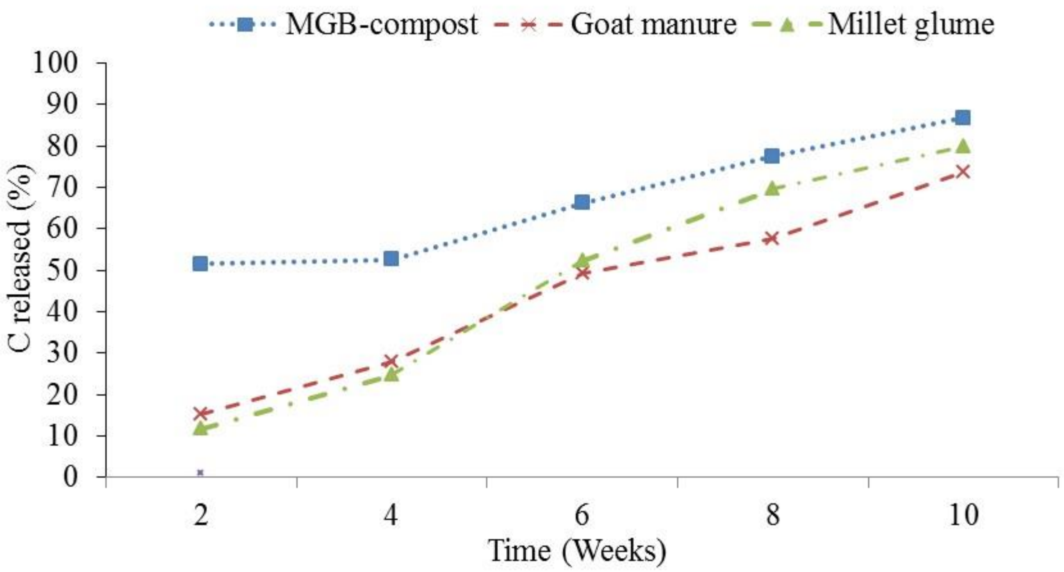


Figure 4.6. Carbon release pattern of MGB-compost, goat manure and millet glume under field conditions

Correlation analysis (Table 4.7) revealed a strong relationship between weight loss and nutrient contents of the organic amendments. There was a strong negative correlation between percentage weight loss and nutrient release from MGB-compost, goat manure and millet glume but this was not the case for K release from goat manure and millet glume.

Table 4.7. Correlation coefficients of relationships between percent weight remaining and nutrient released from organic amendments

	Weight remaining (%)		
Nutrients released	MGB-compost	Goat manure	Millet glume
Total N (%)	-0.969**	-0.974**	-0.983**
Total P (%)	-0.999***	-0.911*	-0.912*
Total K (%)	-0.978**	0.401^{ns}	-0.574^{ns}

ns = not significant at P < 0.05; *, **, and *** significant at P ≤ 0.05, 0.01 and 0.001, respectively

4.2.1.4 Decomposition and nutrient release pattern of MGB-compost under laboratory conditions

This study was conducted to assess the decomposition pattern of the MGB-compost under laboratory conditions.

4.2.1.4.1 Nitrogen release pattern

The MGB-compost treatment showed a decreasing N release rate from 28 to 24 mg kg^{-1} soil from day 14 to 28 days after incubation (Figure 4.7). This was followed by N mineralization till the end of the incubation study which stabilized after 56 days.

4.2.1.4.2 Ammonium - N and nitrate - N release patterns

Ammonium - N was released from MGB-compost treatment throughout the study period (Figure 4.8). The highest ammonium - N release of 22 mg kg^{-1} soil was recorded on the 14^{th} day of incubation. At the end of the incubation period, the ammonium - N release was 17 mg kg^{-1} soil. The MGB-compost treatment showed an increasing nitrate - N release throughout the incubation period (Figure 4.9). The highest rate of nitrate -

N release of 9.6 mg kg^{-1} soil was obtained from the MGBcompost treatment after the 70 days of incubation which coincided with the end of laboratory assessment.

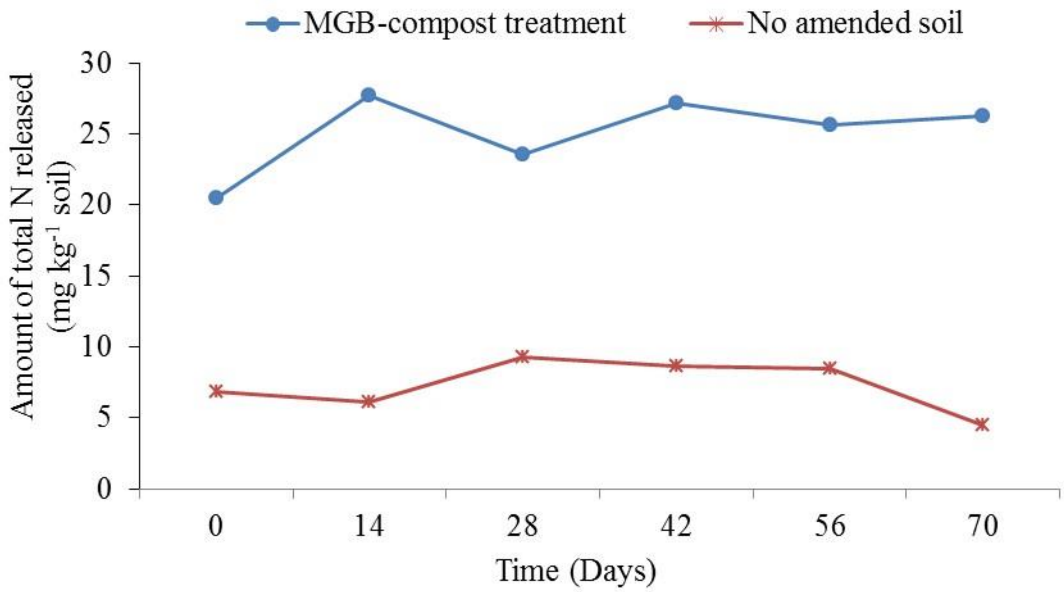


Figure 4.7. Nitrogen release pattern of MGB-compost under laboratory conditions

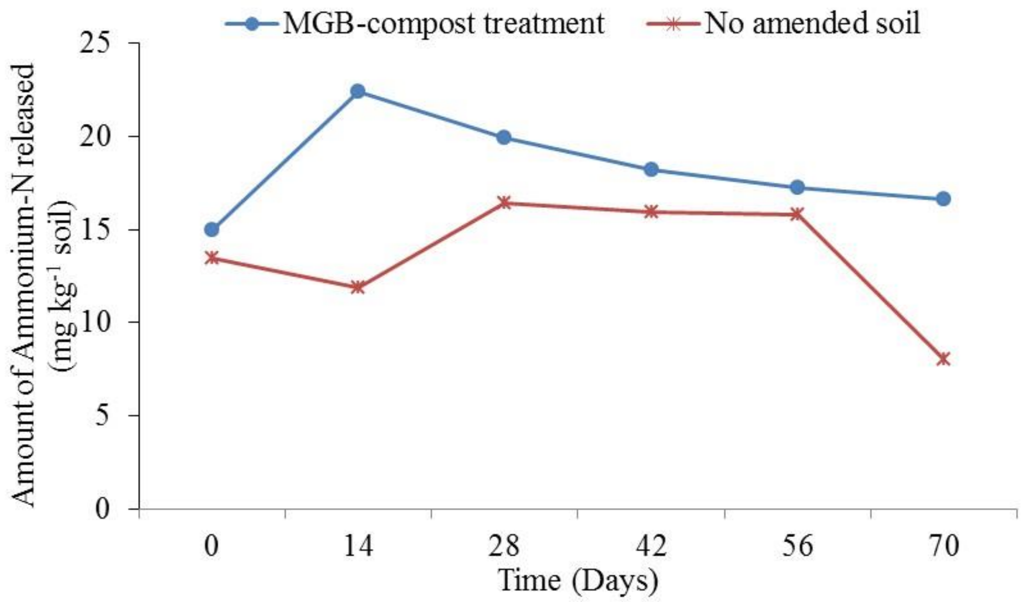


Figure 4.8. Ammonium - N release pattern of MGB-compost under laboratory conditions

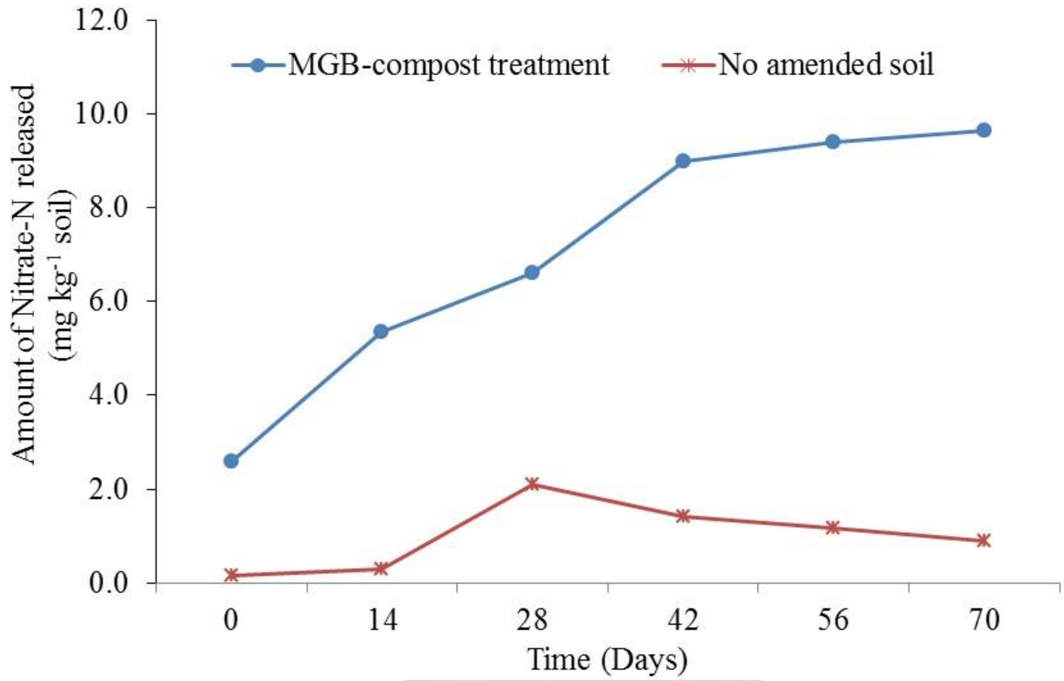


Figure 4.9. Nitrate - N release pattern of MGB-compost under laboratory conditions

4.2.1.4.3 Phosphorus, calcium and magnesium release patterns

The highest (6.8 mg kg^{-1} soil) phosphorus release of MGB-compost treatment was observed during the 14 days of incubation after which it declined up to the end of the incubation period (Figure 4.10). The highest amount of 122 mg kg^{-1} soil of calcium released from MGB-compost treatment was also observed on the 14th day of incubation (Figure 4.11). At the end of the incubation period (70 days), calcium released was 62 mg kg^{-1} soil. As for phosphorus and calcium, the highest (39 mg kg^{-1} soil) magnesium released from MGB-compost treatment was observed on the 14th day of incubation (Figure 4.12). The lowest (12 mg kg^{-1} soil) magnesium released was observed at the 70th day of incubation which coincided with the end of laboratory assessment.

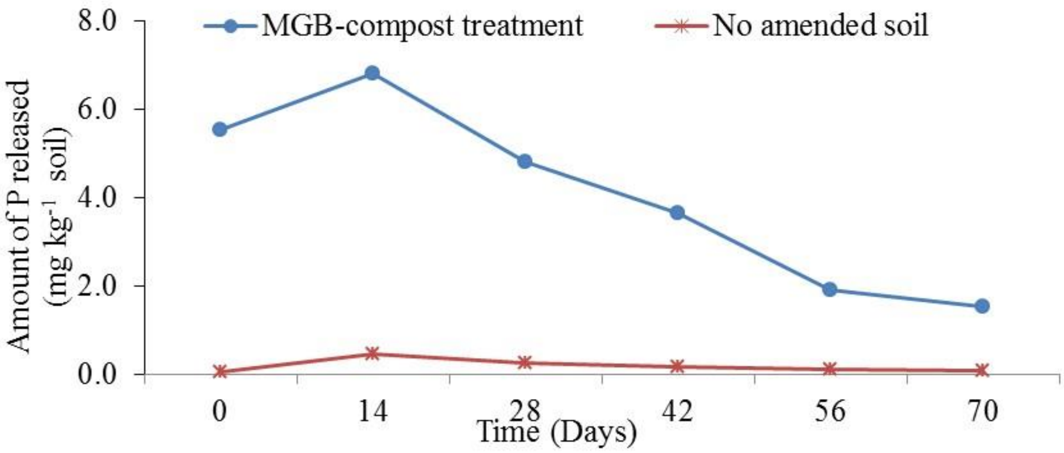


Figure 4.10. Phosphorus release pattern of MGB-compost under laboratory conditions

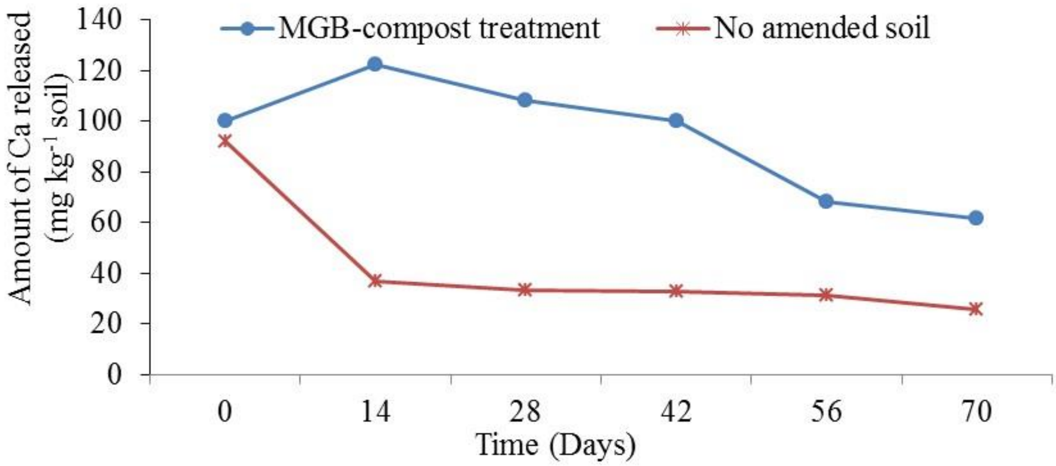


Figure 4.11. Calcium release pattern of MGB-compost under laboratory conditions

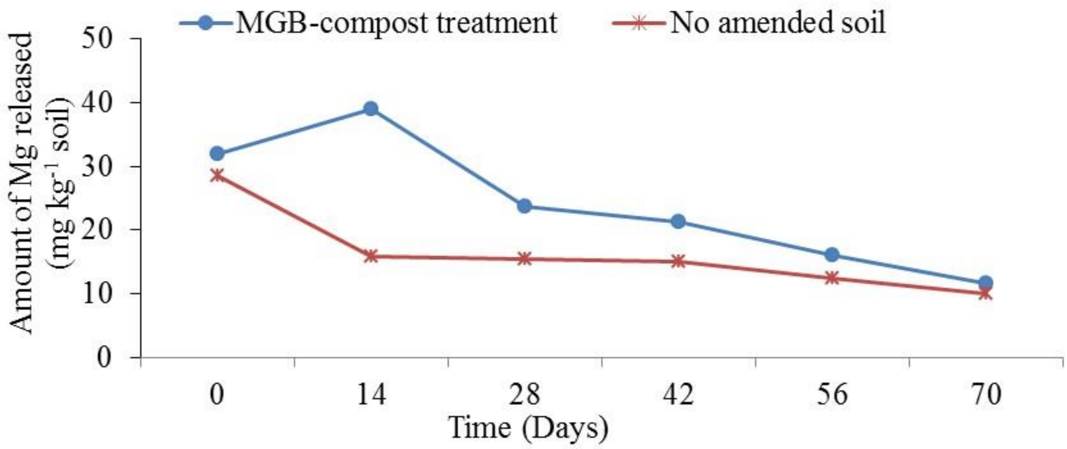


Figure 4.12. Magnesium release pattern of MGB-compost under laboratory conditions

4.2.2 Discussion

4.2.2.1 Chemical composition of MGB-compost

The quality or chemical composition of an organic amendment with respect to its decomposition can be defined as its relative ease of mineralization by decomposer organisms (Paustian *et al.*, 1997; Liu *et al.*, 2006; Shi, 2013). Large differences in the qualities of millet glume and goat manure used for the composting and MGBcompost were observed. The N concentrations of the organic amendments used for this study contained values below 1.0 %. Palm and Sanchez (2000) reported that N immobilization is expected when organic materials with values below 2.5 % of N content are applied to soil. The final N content of compost depends on the N content of the raw materials used for composting. Thus, the fastest decomposition and N mineralization was expected in goat manure which had the highest N concentration and slowest in millet glume.

The critical value below which P immobilization from organic amendment would be expected is 0.25 % (Blair and Boland, 1978). Thus, from this study, phosphorus immobilization would be expected when millet glume is applied (Table 4.4). The P concentrations of goat manure and MGB-compost were above the critical value of 0.25 % and therefore should not result in immobilization. All the organic amendments had low polyphenol and lignin contents which were below the threshold values of 3 to 4 % and 15 %, respectively and above which N immobilization would be expected (Palm and Sanchez, 1991; Palm *et al.*, 2001). Materials with higher lignin concentrations (> 15 %) lead to slow decomposition and N immobilization. Lignin is an aromatic, branched and complex compound, thus, it would require a longer time before decomposition by soil microorganisms. Lignin contributes to the recalcitrance of plant litter to decomposition by occluding more easily decomposable polysaccharides (Madejón *et al.*, 2001; Nolan *et al.*, 2011). All the organic amendments (except MGB-compost) had relatively high concentrations of carbon.

The C:N ratio of the organic amendments were above the critical value of 20 to 25. 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 mineralize N readily (Burgess *et al.*, 2002; Zhu, 2007). Based on existing information (Troeh and Thompson, 2005), the expectation of the relative N release would be MGB-compost > goat manure > millet glume.

The C:P ratio of all the organic materials (except millet glume) was below the critical value of 200:1. Mineralization of P from plant residues would not occur unless the C:P ratio of the residue is lower than 200:1 as observed by Schroth (2003). Other studies have reported the C:P ratio at which mineralization occurs to be variable, ranging from 100 to 300 (Myers *et al.*, 1994). The N:P ratio of MGB-compost was 0.64. The N:P ratio has been suggested as a better indicator for P mineralization (Vogt *et al.*, 1986). Cobo *et al.* (2002) demonstrated that initial quality parameters play an important role for P release among which N:P ratio is pointed as the most influential. The low N concentration of millet glume resulted in the highest PP:N ratio (7.33) (Table 4.5) and consequently, its N would be immobilized when applied to the soil. Seneviratne (2000) found that PP:N ratio determines the N release of plant residues with limited N concentrations. All the organic amendments had L+ PP:N ratio which were above the threshold value of 10 and therefore immobilization of N would be expected to occur as reported by Palm and Sanchez (1991) and Cobo *et al.* (2002). The nutrients immobilized could influence negatively nutrients availability and crop growth as reported by Mohamed (2015).

4.2.2.2 Temperature and its effects on MGB-compost

The pattern of temperature changes in a composting pile has been used to monitor the stabilization of composting process in many studies (Tiquia, 2005; Huang *et al.*, 2006; Szanto *et al.*, 2007). The temperature of MGB-compost was higher than ambient temperature from day 1 to the 57^{th} of composting. The temperature variation during the composting period followed the 3-phase pattern: (i) initial heating phase, (ii) thermophilic phase, and (iii) cooling/maturing phase (Nolan *et al.*, 2011). The recorded variations in temperature during the process indicated microbial activity in the pile as reported by Tomati *et al.* (2000). The maturation phase of the MGBcompost was characterized by a decrease of temperature which was lower than the ambient temperature (Figure 4.1). During this period, the degradation of lignincellulolytics molecules started as demonstrated by Ramdani *et al.* (2015) who worked on co-composting of sewage sludge and green waste. In other works, some authors suggested that temperature could be considered as a good indicator of compost maturity (Brinton, 2000). According to Charnay (2005), the measure of temperature is an indirect index of the degradation intensities.

4.2.2.3 Decomposition and nutrient release pattern of MGB-compost under field conditions

4.2.2.3.1 Decomposition of MGB-compost

Understanding decomposition and nutrient release pattern of organic amendments are necessary because it provides significant indications for improving nutrient synchronization between nutrient release and crop demand (Palm *et al.*, 2001; Brady and Weil, 2010; Partey *et al.*, 2011). In this study, the decomposition and nutrient release of millet glume and goat manure were assessed. The study also evaluated how the composting of millet glume could influence their nutrient release pattern under field conditions. Investigations into decomposer abundance, community composition and temperature were not covered in this study. However, the difference in decomposition and nutrient release pattern between the organic amendments was attributed to the development of different decomposer communities on plant materials based on their intrinsic properties as reported by Cobo *et al.* (2002). Moisture availability, chemical and physical characteristics of the organic amendments were also used to explain of the study results as demonstrated below.

4.2.2.3.1.1 Effect of moisture conditions on decomposition

The moisture condition, quality of litter and the composition of the decomposer community are the three main factors controlling litter decomposition (Cadisch and Giller, 1997; Partey *et al.*, 2011; Partey *et al.*, 2013; Fatoma, 2015). The decomposition pattern of MGB-compost was biphasic with an initial rapid phase followed by a slower phase (Figure 4.2). A similar pattern was observed by Tetteh (2004) and Nhamo *et al.* (2007) working on decomposition of crops residues. The initial rapid phase could be due to the presence of readily digestible water soluble compounds in the organic amendment (Wang *et al.*, 2004) and moisture availability (Fatoma, 2015). Water supply in the form of rainfall (Appendix 5) improved decomposition by facilitating the breakdown of organic amendment. Soil moisture availability leads to good degradation of organic matter through improving faunal and microbial activity (Fatoma, 2015).

4.2.2.3.1.2 Effect of chemical and physical characteristics on decomposition

The chemical composition of plant residues affects how fast it will decompose. Generally, high levels of nutrients, notably nitrogen and lignin, are expected to accelerate and reduce the decomposition process, respectively (Alhamd *et al.*, 2004; Rahman *et al.*, 2013; Pérez-Harguindeguy *et al.*, 2013). Several studies have shown a positive correlation between initial N concentration and the decomposition rate constant (Melillo *et al.*, 1982; Shi, 2013). The findings of this study are however in contrast to that of Melillo *et al.* (1982) and Shi (2013), because goat manure which had the highest N content showed decomposition rate less than MGB-compost. Morphology and tissue structure are important factors governing the colonization of organic amendment by soil microorganisms and consequently the decomposition of amendment in the soil (Chesson *et al.*, 1997; Austin *et al.*, 2014; Motte *et al.*, 2014). Therefore, the surface area and hardness of goat manure and millet glume, respectively compared with MGB-compost may have slowed their colonization by soil biota.

The carbon:nitrogen (C:N) ratio is often used to predict decomposition rate (Clark, 2008; Jensen *et al.*, 2005). MGB-compost with the lowest C:N ratio (28.58) (Table 4.5) decomposed faster than millet glume and goat manure which had a wide C:N ratio of 109.08 and 56.85, respectively. This finding corroborates that of Nhamo *et al.* (2007) who worked on decomposition of crop residues. Polyphenol as well as lignin content of organic materials also influence the rate of decomposition. Polyphenol appears to influence rates of decomposition through their binding to nitrogen in crop residues forming compounds resistant to decomposition (Palm and Sanchez, 1990; Verkaik *et al.*, 2006). In this study, lignin contents of MGB-compost and goat manure were lower relative to that of millet glume. Lignin physically protects cellulose and other carbohydrates from degradation (Chesson *et al.*, 1997). The initial lignin content of millet glume may explain its slow rate of decomposition.

Ezcurra and Becerra (1987) and Shi (2013) contested the applicability of using rates constants obtained from the single exponential model in describing best fitted model for the decomposition of organic materials. However, the high coefficient of determination (R^2) values (Table 4.6) obtained from this study makes the single exponential model seem more applicable. The rapid decomposition was demonstrated by the half-life of MGB-compost of about 4.65 weeks required for the disappearance dry matter in the rainy season relative to 12.38 weeks for millet glume. The higher rate of decomposition of MGB-compost could improve soil nutrient availability and promote crop development.

4.2.2.3.2 Nutrient release pattern of MGB-compost

Nitrogen release from the organic amendments followed different pattern from that of the weight loss. Among the organic amendments, MGB-compost release 87 % of its total N at the end of study period (Figure 4.3). Organic amendments which have a high C:N ratio (millet glume and goat manure), tend to mineralize much more slowly under the same conditions than organic amendments which relatively have lower C:N ratio (e.g. MGB-compost). The N release pattern of the organic amendments used can be explained by its contact with soil which gave more accessibility to microorganisms. The higher microbial activities in the soil could be attributed to soil moisture availability and favorable temperature as reported by Brockett *et al.* (2012). Eighty seven percent N released from MGB-compost was found after 10 weeks of incubation as compared to the fifty percent N released from manure only after 2 weeks (Omare and Woomer, 2002).

Phosphorus released from the organic amendment was higher at the end of the study period in goat manure relative to MGB-compost and millet glume. Kwabiah *et al.* (2003) and Lupwayi *et al.* (2007) reported that phosphorus released during decomposition of organic amendments was positively correlated with P concentration of residue. Fast release of P from goat manure followed by MGBcompost could be attributed to their initial

P content. The results showed that there was P immobilization between 6 and 8 weeks for millet glume. The low P content in the millet glume and high N:P ratio showed that microorganisms depending on soil or their own N content for P mineralization. It was evident from the study that N content influenced P dynamics. Cobo *et al.* (2002) demonstrated that there was a significant correlation between initial quality parameters and nutrient release, N:P ratio for P release being the most important.

Potassium release pattern was very rapid when compared with the other nutrients (Figure 4.5). Potassium immobilization was observed in millet glume and goat manure decomposition from 4 to 6 weeks and 4 to 8 weeks, respectively. The rapid loss of K is expected from an organic material, as this element is not chemically bound to the substrate and also due to its high water solubility. The results of millet glume and goat manure support the assertion reported by Rengel (2007) that leaching is the primary process influencing K losses. However, K release from MGB-compost disagreed with this assertion.

Millet glume and goat manure had the highest carbon content compared with MGBcompost (Table 4.4). However, the amount of carbon released was highest in MGBcompost. This physical characteristic may have slowed a colonization of millet glume and goat manure by soil biota. Arthur (2009) made the same observation working on maize stover decomposition. The very slow decomposition of organic materials like millet glume leads to the accumulation of carbon and buildup of organic matter in the soil. MGB-compost release more nutrients at the end of the study period (10 weeks) which coincided with the millet flowering stage. The nutrients release from MGB-compost could be synchronized with millet nutrient demand up to flowering. Mason *et* *al.* (2015) reported that millet needs more nutrients and water at flowering stage for grain filling.

4.2.2.4 Decomposition and nutrient release pattern of MGB-compost under laboratory conditions

The peak of N release from MGB-compost was observed at the 14 days of incubation (Figure 4.7). The net effect of applying crop residues on the dynamics of soil mineral N and the maximum quantities of N immobilized are related mainly to the concentrations of organic N and C:N ratio of the residue. The initial concentration of N is a better index than the C:N ratio, perhaps because the C:N ratio can be distorted by the presence of appreciable quantities of mineral N (mainly nitrate - N) in the plant tissues, which are thus immediately available (Tian *et al.*, 1992). Palm *et al.* (1997b) have suggested that mineralization of N occurs when C:N ratio of residues are below 25. However, results of the present study showed that rapid initial N release can occur irrespective of MGB-compost C:N ratio. The rapid initial release of N could be attributed to the polyphenol concentration of the amendment. During the early stages of decomposition, it appears that N and polyphenol contents are the main quality parameters that determine mineralization of nitrogen (Gachengo *et al.*, 2004). Polyphenols may control the short - term release of N in organic materials because they are thought to bind to organic - N and render it unavailable for uptake by microbes (Probert *et al.*, 2005). The polyphenol concentrations of MGB-compost were below the critical value of 3 - 4 % at which N immobilization occurs (Palm and Sanchez, 1991) and might have accounted for the release of N from the amendment at the initial stage of the incubation period.

Under adequate soil aeration, moisture and temperature conditions, nitrate - N can be the dominant form of soil N (Hawkes *et al.*, 2005). The result of this study showed that the total N released from MGB-compost was dominated by ammonium -

N (mean of 18 mg kg $^{-1}$ of ammonium - N compared with 7.1 mg kg^{-1} of nitrate - N^{-}). Marschner (2011) reported that the negative charge of nitrate - N makes it much more mobile and thus more prone to loss and thereby less available for plants. However, under certain conditions, plants have preference for using ammonium - N relative to nitrate - N (Boudsocq *et al.*, 2012).

There was initial rapid release of P from MGB-compost. Concentrations of P in MGB-compost were within the commonly reported values of 0.20 to 0.30 % P mineralization threshold level (Khind, 1992; Rick *et al.*, 2011). The initial high P released from MGB-compost could be due to its initial P concentration which was above the threshold levels. The decomposition processes, which are stimulated when organic amendments are incorporated into the soil, can increase availability of P by releasing CO_2, which forms H_2CO_3 in the soil solution, resulting in the dissolution of primary P - containing minerals (Tisdale *et al.*, 1985). The pattern of MGB-compost P release was similar to that reported by Fatoma (2015) working on nutrient dynamics of decomposing water hyacinth.

The MGB-compost released 122 mg kg^{-1} of calcium on the 14th day of incubation. The finding from this study demonstrated that MGB-compost is an organic amendment rich in Ca. The calcium content could be a result of ash added during composting. Wood ash is essentially a direct source of elements such as Ca, Mg, and K (Juárez *et al.*, 2013). Calcium is essential for plant growth and cell division. Calcium is a component of cell membranes and is important for developing plants roots, storage organs and woody tissues (Sanginga and Woomer, 2009). Since Ca is one of the limiting nutrients in the study area (Table 4.8), the application of MGBcompost will supply adequate Ca for plants growth.

4.3 Changes in soil chemical and microbial biomass C, N, P induced by the combined use of MGB-compost, nitrogen and phosphorus fertilizers

4.3.1 Results

4.3.1.1 Soil chemical properties

4.3.1.1.1 Soil pH

The initial soil pH of the experimental site was 5.83 (Table 4.8). Combined application of MGB-compost at 150 g hill^{-1} and N and P fertilizers at 50 % RR (C_{150} g hill^{-1} and 50 % N P_{RR}, RR = recommended rate) recorded a significantly ($P = 0.002$) higher soil pH of 6.87 while the sole application of 100 % N P_{RR} treatment recorded the lowest value of 5.20 during the 2013 cropping season. In the 2014 cropping season, the increase in soil pH of 6.80 was more pronounced in the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} (Table 4.9). Generally, the two years application of MGB-compost with or without N and P fertilizers increased soil pH from 5.20 to 6.80.

4.3.1.1.2 Organic carbon

The initial soil organic carbon (OC) content of the experimental site was 0.08 % (Table 4.8). Changes in soil organic carbon content following the application of different amendments revealed that the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} led to a significantly ($P < 0.001$) higher OC level relative to the other treatments during the 2013 cropping season. In general, soil OC content in the treatments was more than that of the control during the 2014 cropping season. After the application of MGB-compost for two seasons, the combined application of C_{300} g hill^{-1} and 100 % N P_{RR}

treatment gave the highest OC of 0.31 %. The lower values of OC content were obtained in sole applications of N and P fertilizers and the control treatments (Table 4.9).

4.3.1.1.3 Total N

There were a significant differences (P = 0.002) in soil total N among the treatments following the application of MGB-compost and N and P fertilizers in 2013 cropping season. During the 2013 cropping season, the sole application of C_{300} g hill^{-1} and combined application of C_{300} g hill^{-1} and 100 % N P_{RR} recorded the highest value of 0.03 % while the lowest value was recorded by the control (C_0 g hill^{-1} and 0 % N P_{RR}) and sole application of N and P fertilizers treatments (Table 4.9). In the 2014 cropping season, the highest soil total N of 0.15 % was recorded in the sole application of C_{300} g hill^{-1} and combined application of C_{300} g hill^{-1} and 100 % N P_{RR} (Table 4.9).

Table 4.8. Initial soil chemical properties of the experimental site

Measured parameters	**Soil depth (0-15 cm)**
pH (1:2.5 H_2O)	5.83
Organic carbon (%)	0.08
Total N (%)	0.01
Available P (mg kg^{-1})	13.57
Exchangeable bases (cmol$_{(+)}$ kg^{-1})	
Calcium (Ca^{2+})	0.64
Magnesium (Mg^{2+})	0.17
Potassium (K^{+})	0.06
Sodium (Na^{2+})	0.06
Exchangeable acidity (Al^{3+} + H^{+}) (cmol$_{(+)}$ kg^{-1})	0.03
Effective cation exchange capacity (cmol$_{(+)}$ kg^{-1})	0.96

4.3.1.1.4 Available P

The initial available P content of the experimental site was 13.57 mg kg^{-1} (Table 4.8). During the 2013 cropping season, available soil P content under the sole application of C_{300} g $hill^{-1}$ gave the highest value of 30.97 mg kg^{-1}. The lowest value of 8.81 mg kg^{-1} was recorded for the sole application of 50 % N P_{RR} (Table 4.9). Significant ($P < 0.001$) differences were recorded between the treatments during the 2014 cropping season. The highest value of 50.22 mg kg^{-1} was obtained for the combined application of C_{300} g $hill^{-1}$ and 100 % N P_{RR} while the lowest value was recorded for the control. There was a significant interaction ($P < 0.001$) between year and treatments applied on available P (Appendix 6).

4.3.1.1.5 Exchangeable bases

Changes in exchangeable bases (Ca, Mg, K and Na) contents of the soil following the application of the different amendments are presented in Table 4.10. The initial exchangeable Ca of the experimental site was 0.64 $cmol_{(+)}$ kg^{-1} (Table 4.8). During the 2013 cropping season, exchangeable Ca content was lowest (0.50 $cmol_{(+)}$ kg^{-1}) under the control while the sole application of C_{300} g $hill^{-1}$ treatment had the highest value of 0.99 $cmol_{(+)}$ kg^{-1}. Generally, there was a significant ($P < 0.001$) increase in the Ca content of the treatments applied more than that of the control during the 2014 cropping season. During the 2013 cropping season, exchangeable Mg content under sole application of C_{300} g $hill^{-1}$ treatment had the highest value of 1.53 $cmol_{(+)}$ kg^{-1} while the lowest value of 0.15 $cmol_{(+)}$ kg^{-1} was recorded for the 100 % N P_{RR} treatment. There was a significant difference ($P < 0.001$) among the treatments in the exchangeable Mg content during the 2014 cropping season (Table 4.10).

Combined application of C_{300} g hill^{-1} and 100 % N P_{RR} gave the highest K value of 0.33 cmol$_{(+)}$ kg^{-1} followed by that of the sole application of C_{150} g hill^{-1} with a value of 0.23 cmol$_{(+)}$ kg^{-1} during the 2013 cropping season. There were significant ($P <$ 0.001) differences among the treatments in K content during 2014 cropping season (Table 4.10). The exchangeable Na content recorded for the 2013 cropping season ranged between 0.05 and 0.14 cmol$_{(+)}$ kg^{-1}. It was also observed that there was an increase in exchangeable Na content during 2014 cropping season except for sole application of 100 % N P_{RR} and combined application of C_{300} g hill^{-1} and 50 % N P_{RR} treatments (Table 4.10). Generally, the annual application of the various treatments improved soil exchangeable bases of the amended plots.

Table 4.9. Effect of MGB-compost, N and P fertilizers on soil pH, OC, total N and available P

Treatments	pH		OC (%)		Total N (%)		Avail.P (mg kg^{-1})	
	2013	2014	2013	2014	2013	2014	2013	2014
						0.04		
C_0 + 50% N P_{RR}	5.73	5.63	0.07	0.14	0.01	0.06	8.81	11.97
C_0 + 100% N P_{RR}	5.20	5.40	0.09	0.11	0.01	0.08	11.99	13.10
C_{150} + N_0 P_{0RR}	6.30	6.57	0.20	0.17	0.02	0.11	25.37	35.78
C_{150} + 50% N P_{RR}	6.87	6.13	0.25	0.26	0.02	0.11	22.83	33.77
C_{150} + 100% N P_{RR}	6.77	5.93	0.12	0.28	0.02	0.13	18.63	45.23
C_{300} + N_0 P_{0RR}	5.83	6.57	0.18	0.21	0.03	0.15	30.97	40.94
C_{300} + 50% N P_{RR}	6.40	6.73	0.20	0.23	0.02	0.14	26.84	45.21
C_0 + N_0 P_{0RR}	5.90	5.80	0.06	0.11	0.01		10.21	10.38

C_{300} + 100% N P_{RR}	6.50	6.80	0.30	0.31	0.03	0.15	30.79	50.22
Probability (P)	0.002	0.006	< 0.001	< 0.001	0.002	0.002	< 0.001	< 0.001
L.s.d (5%)	0.70	0.74	0.10	0.08	0.01	0.05	4.77	5.14
CV (%)	6.7	6.9	35.7	22.4	26.6	27.5	13.3	9.3

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied; Avail. P = available P

Table 4.10. Effect of MGB-compost, N and P fertilizers on soil Ca, Mg, K and Na

	Exchangeable bases ($cmol_{(+)}\ kg^{-1}$)							
Treatments	Ca		Mg		K		Na	
C_0 + 50% N P_{RR}	0.64	0.90	0.23	2.04	0.12	0.03	0.08	0.09
C_0 + 100% N P_{RR}	0.87	0.99	0.15	2.07	0.10	0.02	0.10	0.10
C_{150} + N_0 P_{0RR}	0.81	0.92	0.16	2.16	0.23	0.15	0.11	0.15
C_{150} + 50% N P_{RR}	0.84	1.15	1.00	2.04	0.19	0.18	0.10	0.11

	2013	2014	2013	2014	2013	2014	2013	2014
C_{150} + 100% N P_{RR}	0.83	0.94	1.26	2.28	0.15	0.14	0.10	0.14
C_{300} + N_0 P_{0RR}	0.99	0.97	1.53	2.26	0.21	0.23	0.08	0.20
C_{300} + 50% N P_{RR}	0.95	0.96	1.08	2.11	0.21	0.17	0.14	0.10
C_0 + N_0 P_{0RR}	0.50	0.48	0.40	1.14	0.05	0.03	0.05	0.10
C_{300} + 100% N P_{RR}	0.96	1.06	1.37	2.08	0.33	0.48	0.11	0.14
Probability (P)	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.003	< 0.001
L.s.d (5%)	0.20	0.18	0.12	0.18	0.05	0.04	0.03	0.04
CV (%)	13.8	11.4	9.0	5.3	16.6	13.7	20.6	17.1

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied

4.3.1.1.6 Exchangeable acidity

During the 2013 cropping season, the sole application of 100 % N P_{RR} treatment had the highest value (0.05 $cmol_{(+)}$ kg^{-1}) of exchangeable acidity. Generally, all the treatments either showed a decline or maintained the exchangeable acidity content during the 2014 cropping season relative to 2013 cropping season values (Table 4.11). The change was more pronounced in the MGB-compost amended plots. Furthermore, the annual application of MGB-compost as organic amendment contributed to reduced soil acidity.

4.3.1.1.7 Effective cation exchange capacity

The effective cation exchange capacity of the soil recorded during the 2013 cropping season ranged between 1.04 and 2.84 $cmol_{(+)}$ kg^{-1}. The effective cation exchange capacity values were significantly ($P < 0.001$) varied among the treatments during the 2014 cropping season. The control gave the lowest mean value of 1.40 $cmol_{(+)}$ kg^{-1} while the combined application of C_{300} g $hill^{-1}$ and 100 % N P_{RR} treatment gave the highest mean value of 3.29 $cmol_{(+)}$ kg^{-1} after the two cropping seasons (Table 4.11).

Table 4.11. Effect of MGB-compost, N and P fertilizers on soil exchangeable acidity and ECEC

Treatments	Exch. acidity (cmol$_{(+)}$ kg^{-1})		ECEC (cmol$_{(+)}$ kg^{-1})	
	2013	2014	2013	2014
$C_0 + N_0 P_{0RR}$	0.02	0.03	1.04	1.77
C_0 + 50% N P_{RR}	0.02	0.02	1.09	3.08
C_0 + 100% N P_{RR}	0.05	0.03	1.27	3.22
$C_{150} + N_0 P_{0RR}$	0.02	0.02	1.34	3.39
C_{150} + 50% N P_{RR}	0.03	0.02	2.15	3.50
C_{150} + 100% N P_{RR}	0.03	0.02	2.37	3.53
$C_{300} + N_0 P_{0RR}$	0.02	0.02	2.84	3.68
C_{300} + 50% N P_{RR}	0.02	0.02	2.40	3.36
C_{300} + 100% N P_{RR}	0.03	0.03	2.70	3.80
Probability (P)	< 0.001		< 0.001	< 0.001
L.s.d (5%)	0.008	0.009	0.228	0.30
CV (%)	17.4	23.0	6.9	5.3

0.009

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied, Exch. Acidity = exchangeable acidity; ECEC = effective cation exchange capacity

4.3.1.2 Selected soil physical properties of the experimental site

4.3.1.2.1 Soil particle size

The particle size analysis of the 0 - 15 cm soil depth showed that over 95 % of the particles were sand-sized whereas silt-sized particles represented less than 3 % (Table 4.12). Clay-sized particles at the onset of 2013 cropping season and at end of 2014 cropping season constituted 2.98 and 3.06 % of the particles, respectively. The texture of the soils of experimental site was sand.

Table 4.12. Soil physical properties of the experimental site

Particle size*	Site characterization	
	Onset of 2013 cropping season	End of 2014 cropping season
Sand (%)	96.28 (±0.35)	95.80 (±0.26)
Silt (%)	2.21 (±0.43)	1.64 (±0.25)
Clay (%)	2.98 (±0.07)	3.06 (±0.50)
Textural class	Sand	Sand

*Values are average of four replicates; values in parenthesis represent standard error.

4.3.1.2.2 Soil moisture content, bulk density and porosity

The effects of the different amendments on soil moisture content and bulk density are presented in Table 4.13. There was a significant interaction ($P = 0.016$) between MGB-compost and N and P fertilizers on soil moisture content and bulk density at millet tillering, flowering and maturity. Soil moisture content was significantly ($P < 0.001$) higher under the plots treated with MGB-compost relative to those of N and P fertilizers (Table 4.13).

There was also a significant interaction ($P = 0.007$) between the MGB-compost and N and P fertilizers on volumetric moisture content and porosity at millet tillering, flowering and maturity. Soil volumetric moisture content and porosity were significantly ($P < 0.001$) higher under the plots treated with MGB-compost relative to those of N and P fertilizers treatments (Table 4.13). Generally, the two years application of MGB-compost improved soil moisture content parameters more than plots without the application of MGB-compost.

Table 4.13. Multivariate analysis of the effect of MGB-compost, N and P fertilizers on soil moisture content, bulk density and porosity

MONOVA for moisture content and bulk density		
Response variables: tillering, flowering, maturity		
Effect	Wilk's Lambda	Probability
Compost	0.003	< 0.001
N and P fertilizers	0.813	0.578
Compost x N and P fertilizers	0.353	0.016
MONOVA for volumetric moisture content and porosity		
Response variable: tillering, flowering, maturity		
Effect	Wilk's Lambda	Probability
Compost	0.003	< 0.001
N and P fertilizers	0.761	0.391
Compost x N P fertilizers	0.323	0.007

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied; tillering = 30 days after sowing (DAS), flowering = 64 DAS, maturity = 83 DAS.

4.3.1.3 Soil microbial biomass carbon, nitrogen and phosphorus

The results from the soil analysis at the onset of the 2013 cropping season showed only traces of microbial biomass carbon, nitrogen and phosphorus. At millet harvest of 2013 cropping season, soil microbial biomass carbon was significantly ($P < 0.001$) higher under the combined application of C_{300} g hill^{-1} and 50 % N P_{RR} and C_{300} g hill^{1} and 100 % N P_{RR} treatments (0.32 %) (Table 4.14). The N and P fertilizers treatments had the lowest biomass carbon of 0.03 %. Generally, soil microbial biomass carbon increased in the treatments amended with MGB-compost more than that of the control during the 2014 cropping season.

The trend observed for microbial biomass nitrogen was similar to that of the microbial biomass carbon. The combined application of C_{300} g hill^{-1} and 50 % N P_{RR} had the highest microbial biomass nitrogen (0.031 %) during the 2013 cropping season followed by that of the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} treatment (0.028 %). The lowest value of 0.001 % was recorded for the control and sole application of N and P fertilizers treatments. However, the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} treatment gave the highest (0.054 %) microbial biomass nitrogen during the 2014 cropping season.

The sole application of C_{300} g hill^{-1} treatment recorded the highest (6.09 mg kg^{-1}) microbial biomass P during the 2013 cropping season followed by the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} treatment (5.68 mg kg^{-1}). The lowest value of 0.88 mg kg^{-1} was recorded for the control treatment. However, the value for microbial biomass phosphorus increased in 2014 cropping season from 1.99 to 15.11 mg kg^{-1} (Table 4.14). The annual application of the treatments significantly ($P < 0.001$) increased the microbial biomass carbon, nitrogen and phosphorus content of the soil during the 2013 and 2014 cropping seasons. Soil microbial biomass was generally more pronounced on the MGB-compost plots with or without N and P fertilizers (Table 4.14).

Table 4.14. Effect of MGB-compost, N and P fertilizers on soil microbial biomass carbon, nitrogen and phosphorus

Treatments	MBC (%)		MBN (%)		MBP (mg kg^{-1})	
	2013	2014	2013	2014	2013	2014
$C_0 + N_0 P_{0RR}$	0.03	0.02	0.001	0.001	0.88	1.99
C_0 + 50% N P_{RR}	0.03	0.02	0.001	0.002	1.10	2.08
C_0 + 100% N P_{RR}	0.03	0.15	0.002	0.002	1.96	3.27
$C_{150} + N_0 P_{0RR}$	0.24	0.35	0.023	0.040	2.48	5.86
C_{150} + 50% N P_{RR}	0.19	0.28	0.014	0.030	2.71	7.49
C_{150} + 100% N P_{RR}	0.15	0.23	0.021	0.021	2.71	6.63
$C_{300} + N_0 P_{0RR}$	0.27	0.43	0.023	0.026	6.09	13.95
C_{300} + 50% N P_{RR}	0.32	0.34	0.031	0.053	4.36	15.11
C_{300} + 100% N P_{RR}	0.32	0.27	0.028	0.054	5.68	12.58
Probabilty (P)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
L.s.d (5%)	0.023	0.084	0.001	0.008	0.574	0.894
CV (%)	7.7	20.9	1.9	15.6	10.7	6.7

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied; MBC = microbial biomass carbon; MBN = microbial biomass nitrogen; MBP = microbial biomass phosphorus

4.3.1.3.1 Microbial quotient

Microbial quotient (Cmic/Corg) represents the amount of metabolic active carbon in the total soil organic matter. Cmic/Corg is generally considered as sensitive change indicator of soil organic matter quality. Microbial quotient of the treatments under consideration varied from 0.22 to 1.80 (Table 4.15). The highest ratio was recorded under sole application of C_{300} g hill^{-1} while the lowest was recorded for the sole application of 50 % N P_{RR}. There was a significant interaction (P = 0.037) between year and treatments applied on soil microbial quotient (Table 4.15).

Table 4.15. Effect of MGB-compost, N and P fertilizers on soil microbial quotient

Treatments	Microbial biomass carbon (%)	Soil organic carbon (%)	Microbial quotient
C_0 + N_0 P_{0RR}	0.02	0.09	0.27
C_0 + 50% N P_{RR}	0.02	0.11	0.22
C_0 + 100% N P_{RR}	0.09	0.10	0.95
C_{150} + N_0 P_{0RR}	0.30	0.19	1.58
C_{150} + 50% N P_{RR}	0.23	0.26	0.91
C_{150} + 100% N P_{RR}	0.19	0.20	0.95
C_{300} + N_0 P_{0RR}	0.35	0.19	1.80
C_{300} + 50% N P_{RR}	0.33	0.21	1.54
C_{300} + 100% N P_{RR}	0.30	0.31	0.96
Year (Prob.)	0.045	0.048	0.040
Treatment (Prob.)	< 0.001	< 0.001	< 0.001
Year *x* treatment (Prob.)	< 0.001	0.177	0.037
L.s.d - treatment (5%)	0.042	0.062	0.597
CV (%)	17.4	28.6	46.1

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied

4.3.1.3.2 Relationship between soil microbial biomass, soil nutrients and moisture content

Correlation analyses showed a relationship between soil chemical, moisture content and microbiological properties (Tables 4.16, 4.17 and Figures 4.13, 4.14 and 4.15). Soil exchangeable bases had a positive correlation ($P \leq 0.05$) with microbial biomass carbon (Table 4.16). A strong relationship ($P < 0.001$) was observed between soil volumetric moisture content and microbial biomass P (Table 4.17) and biomass carbon had significant ($P = 0.01$) linear relationship with soil organic carbon (Figure 4.13). A significant linear relationship ($P = 0.001$) was also established between microbial biomass P and soil available P (Figure 4.15).

Table 4.16. Correlation coefficients between MBC and soil exchangeable bases after two years of amendment application

MBC	1					
Ca	0.731*	1				
K	0.768*	0.644^{ns}	1			
Mg	0.755*	0.782*	0.686*	1		
Na	0.912***	0.731*	0.643^{ns}	0.766*	1	
ECEC	0.823**	0.887**	0.792*	0.858***	0.812**	1
	MBC	Ca	K	Mg	Na	ECEC

MBC = microbial biomass carbon; Ca = calcium; K = potassium; Mg = magnesium; Na = sodium; ECEC = effective cations exchangeable capacity; ns = not significant at $P < 0.05$; *, **, and *** significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

Table 4.17. Correlation coefficients between microbial biomass and soil volumetric moisture content after two years of amendment application

VMC	1

MBC	0.87**	1		
MBN	0.82**	0.86**	1	
MBP	0.88***	0.90***	0.81**	1
	VMC	MBC	MBN	MBP

VMC = volumetric moisture content; MBC = microbial biomass carbon; MBN = microbial biomass nitrogen, MBP = microbial biomass phosphorus; *, **, and *** significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

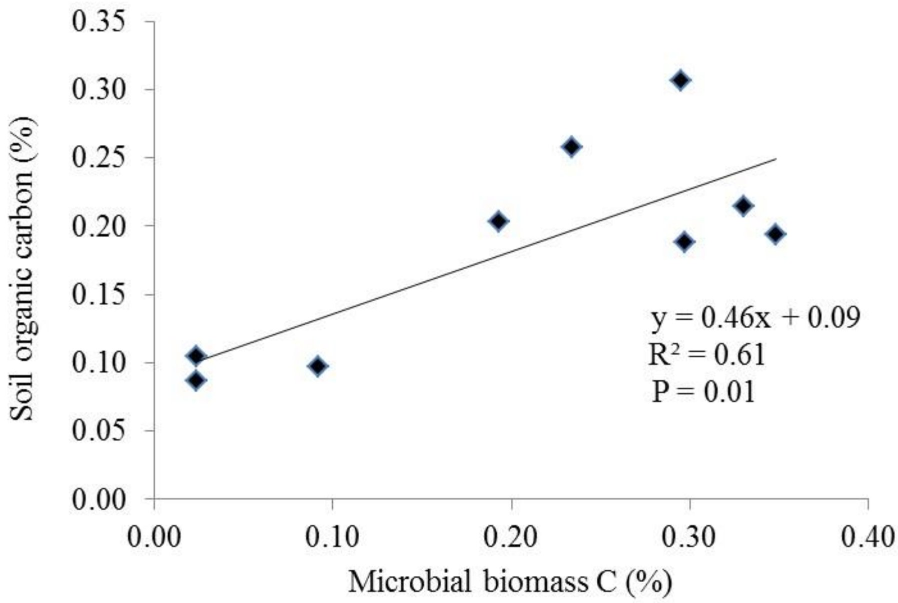


Figure 4.13. Relationship between soil organic carbon and microbial biomass C after two years of amendment application

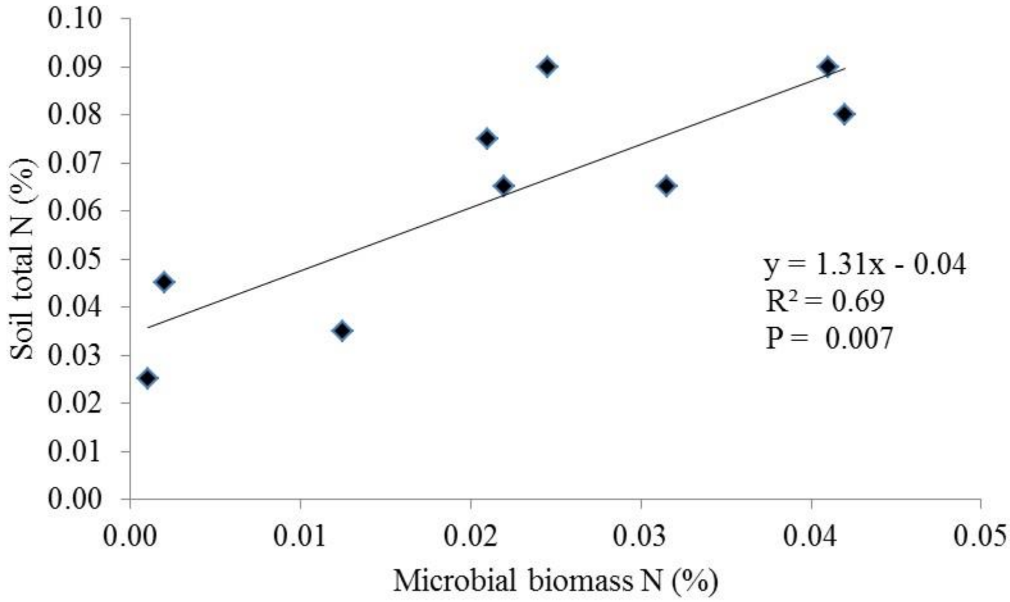


Figure 4.14. Relationship between soil total N and microbial biomass N after two years of amendment application

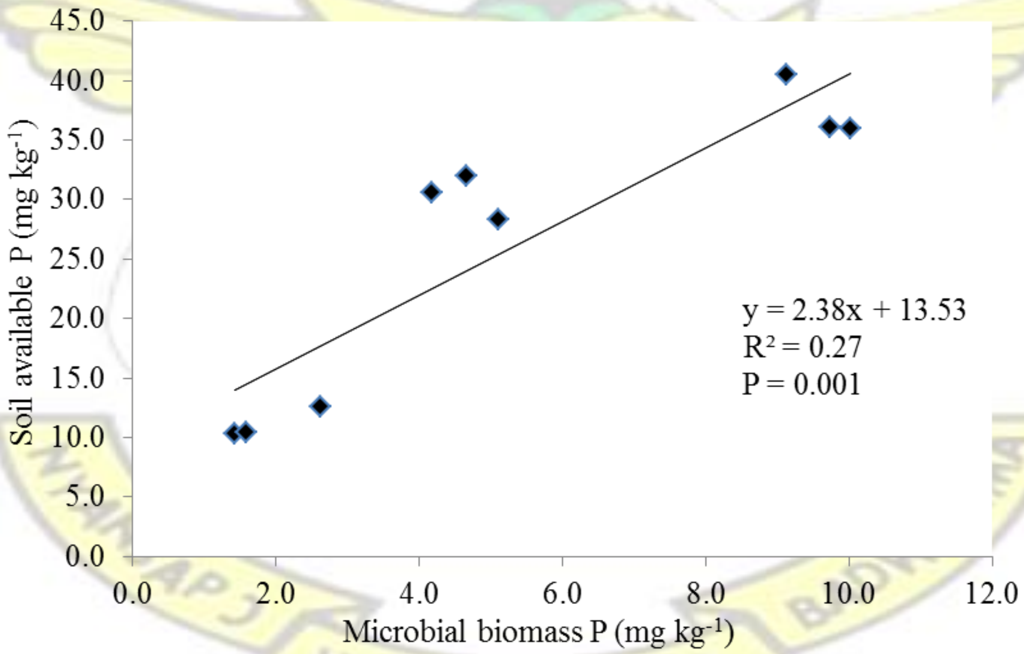


Figure 4.15. Relationship between soil available P and microbial biomass after two years of amendment application

4.3.2 Discussion

4.3.2.1 Soil chemical properties

4.3.2.1.1 Soil organic carbon, nitrogen and phosphorus

Following the classification of Landon (2014), the percentage of initial soil organic carbon content of experimental site was very low. This could be ascribed to limited addition of organic materials and the continuous cropping over the past years. Soil organic carbon contents were relatively higher in plots amended with MGB-compost relative to the control and the sole application of N and P fertilizers treated plots. The annual application of MGB-compost showed an increase in soil organic carbon content of the experimental plots. Addition of organic fertilizer improves soil organic carbon (Shibabaw and Melkamu, 2015). Ding *et al.* (2012) earlier reported that graded application rates of manure from lower to higher levels significantly enhanced total soil organic carbon as compared with the control. The increases in soil organic carbon recorded in 2014 cropping season are probably due to residual effect of MGB-compost on soil organic carbon over the two-year cropping period. This is in close agreement with the finding of Demelash *et al.* (2014) who reported an increase in soil organic carbon up to 104 % as a result of two years of compost application.

The value recorded for initial total N (0.01 %) was very low following Landon"s rating (Landon, 2014). Nitrogen is an essential component of organic matter. The initial low amount of total N obtained was therefore as result of the low organic matter content of the soil. Soil total N was 2 times higher on MGB-compost amended plots relative to the control plot at the end of the study period. This observation was possibly due to mineralization especially in the MGB-compost amended plots. It has been shown that soils which receive organic matter inputs on a regular basis generally have greater N supplying ability than soils which receive only inorganic amendments (Schlecht *et al.*, 2006). Working on manure and compost made from household wastes, Bouajila and Sanaa (2011) also reported that organic amendment types increased significantly both soil organic carbon and nitrogen contents.

The initial available P content (13.57 mg kg^{-1}) of the experimental soil was medium (Page, 1982) (Table 4.8). Landon (2014) reported that low phosphorus values certainly indicate deficiencies. However, phosphorus value less than 2 mg P kg^{-1} was reported by Adamou *et al.* (2007) working on sandy soils in Niger. Changes in soil available P (after one year application of phosphorus) were generally higher in all amended plots when compared to the initial values except the sole application of N and P_{RR} fertilizers at 50 % and 100 % treatments. From 2013 to 2014 cropping seasons, the increases of available P were generally higher in plots treated with MGB-compost and N and P fertilizers treatments. Several studies have shown that organic materials may increase agricultural P by improving the availability of phosphorus already in the system (Palm *et al.*, 1997b; Richardson *et al.*, 2009). The incorporation of crop residues has been shown to increase the amount of soluble organic matter which are mainly organic acids that increase the rate of desorption of phosphate and thus improves the available P content in the soil (Nziguheba *et al.*, 1998). Increase in P availability in plots amended with MGB-compost during the 2014 cropping season could be due to the residual effect resulting from the 2013 and 2014 cropping seasons (Table 4.9). Soil available P levels increased with continued application of composts (Sharpley *et al.*, 1997; Schlecht *et al.*, 2006). Baziramakenga *et al.* (2001) demonstrated that composted mixture of paper sludge and poultry manure increased the extractable P in soils. The result of the present study demonstrated the positive contribution of annual application of MGB-compost in terms of soil P availability especially during 2014 cropping season where P was not applied.

4.3.2.1.2 Soil exchangeable bases and acidity

The initial soil sample recorded a low amount of calcium (0.64 $cmol_{(+)}$ kg^{-1}) as rated by Landon (2014). The initial Mg content of the soil was 0.17 $cmol_{(+)}$ kg^{-1} and can be classified as low. The Ca:Mg ratio was 3.76 at the onset of the 2013 cropping season. Magnesium content of the soil is closely related to the presence of other cations, particularly Ca and K. Increasing Ca:Mg ratio above 5:1 makes magnesium less available to plants, even though soils can remain fertile over a wide range of Ca:Mg ratio (Landon, 2014). At the end of the study period, Ca:Mg ratio was between 0.50 and 0.83 on plots amended with MGB-compost alone or in combination with N and P mineral fertilizers. The initial exchangeable K content of the experimental plot was 0.06 $cmol_{(+)}$ kg^{-1}. The application of amendments had improved the K content of the experimental site from 0.06 to 0.40 $cmol_{(+)}$ kg^{-1}. Exchangeable cations including Ca, Mg and K were significantly higher on plots where MGB-compost was applied. This may be due to the initial high content of these elements in the MGB-compost (Table 4.4) resulting from the addition of ash during composting. This finding confirms the result of Hafidi *et al.* (2012) and Oo *et al.* (2015) who reported an increase in Ca content with the application of compost. According to Sarwar *et al.* (2008) an increase in Ca and Mg from compost application could be due to the reaction of organic acids with $CaCO_3$ and Mg salts. However, soil rich in Ca may lead to Mg deficiency (Sanginga and Woomer, 2009).

The initial soil pH of the experimental plot was 5.83 (Table 4.8). Based on the rating reported by Landon (2014), the initial pH of the soil was acidic. The MGB-compost with or without N and P fertilizers treatments were able to increase the pH level of the soil through the supply of basic cations as a result of ash added in the compost. Compost protects soil from leaching of basic cations and thus prevents it from becoming acidic (Elbl *et al.*, 2013). Abdel-Rahman (2009) and Merwad and AbdelFattah (2015) demonstrated that soil pH increased from 6.7 to 7.5 and 8.15 by compost and manure application, respectively. At the end of the study period, the N and P fertilizers treatments and the control had averagely the lowest pH. The low pH recorded under the sole application of N and P fertilizers treatments might be due to acidification of the soil by the urea fertilizer applied over the two years. Cai *et al.* (2015) also observed that the application of urea fertilizer led to soil acidification from the initial of 5.7 to 4.5 after application. After two years of amendment application, the pH of the experimental site ranged averagely from 5.30 to 6.65. It is important to determine soil pH, for crop cultivation because many plants and soil organisms have a preference for acidic or slight alkaline conditions and thus it influences their vitality (Fischer and Glaser, 2012). The range of soil pH found in the current study was adequate for increasing plant nutrients availability such as nitrogen, phosphorus, potassium, calcium and magnesium.

4.3.2.2 Soil moisture content

The application of MGB-compost increased soil moisture content at millet tillering, flowering and maturity (Table 4.13, Appendix 8). Adequate soil moisture content is effective for enhanced plant growth. Low soil moisture content could have water stress on crops at the early stages of growth. Increasing the moisture of soils provides more available water to plants and can also help in resistance to drought (Blum, 2005). Application of organic residues could increase soil organic matter and enhance water retention capacity (Spaccini *et al.*, 2002). Edwards *et al.* (2000) found that compost made from a mixture of potatoes, sawdust and manure increased soil moisture over that of untreated soil. Earlier study of Charles Gould (2012) demonstrated that organic matter holds a lot water, thus, the application of organic matter in a soil improves the availability of water to a crop over time.

4.3.2.3 Soil microbial biomass carbon, nitrogen and phosphorus

Soil organic matter favors the growth of bacteria present in the soil (Bilkisu and Babatunde, 2015). High level of microbial biomass carbon was recorded on the plots amended annually with MGB-compost. According to Peacock *et al.* (2001), the decomposition rate of an organic input is responsible for the variation in the level of microbial biomass. Although the quantity of microbial biomass is mainly related to carbon input. Carbon is mainly used as an energy source for building microbial cells (Sweeten and Auvermann, 2008). The effect of compost on soil might have been resulted from the role of compost in improving soil microbial activities which enhanced nutrient mobilization from organic and inorganic fertilizers to plant (Ibrahim *et al.*, 2008; Yassen *et al.*, 2010).

Microbial biomass nitrogen was lower under sole application of mineral fertilizer treatments relative to those of the treatments which received MGB-compost. Lovell and Jarvis (1998) reported that regular applications of nitrogen alone led to a decrease in the content of soil microbial biomass N. Furthermore, regular use of acidulated fertilizer generally contribute to the accumulation of acidity in soil, which progressively increases aluminum availability and hence toxicity and death of soil microbes (Schrack, 2009).

Microbial biomass P recorded during 2013 cropping season was significantly lower than that in the 2014 cropping season (Appendix 6). Many soils chemically fix P on their surfaces, where it is then removed from plant - available pool (Brookes, 2001). Microbial biomass P was higher on plots treated with MGB-compost than those treated with N and P fertilizers and the control plots. Organic matter additions may decrease P fixation by masking sites which would usually fix P. Significant linear relationship (P = 0.001) was established between microbial biomass P and soil available P (Figure 4.15). The microbial biomass which decomposes the compost will also have large demand for P as it grows. Thus, P will be immobilized within the microbial cells and so be protected from fixation by the soil colloids. As the microbial biomass declines, following the degradation of the compost, microbial biomass P will be mineralized to available P, which plants can readily use again (Brookes, 2001; Malik *et al.*, 2013).

4.3.2.3.1 Microbial quotient

Microbial quotient represents the amount of metabolic active carbon in the total soil organic matter. Microbial quotient is generally considered as sensitive changes indicator of soil organic matter quality (Insam and Domsch, 1988; Sparling, 1992). Soil microbial quotient was high under the plots treated with MGB-compost (Table 4.15). The significant increase in microbial quotient was probably due to the organic carbon added in the soil through the application of MGB-compost. The values in this study ranged from 0.22 to 1.80 and were lower than the values (1.98 to 4.41) reported by Maková *et al.* (2012). Meyer *et al.* (1997) earlier demonstrated that in surface horizons microbial quotient below 1.0 usually indicates a disturbed turnover of soil

organic matter. The decrease in microbial quotient could be related to a significant increase of microbial diversity in soil because a diverse microbial community is able to better transform carbon from organic debris into biomass
(Mäder *et al.*, 2002), consequences for soil health and crop productivity.

4.4 Influence of MGB-compost, nitrogen and phosphorus fertilizers on millet/cowpea yields

4.4.1 Results

4.4.1.1 Millet grain yield

Millet grain yield in response to the application of MGB-compost, N and P fertilizers during the 2013 and 2014 cropping seasons are presented in Table 4.18. During the 2013 cropping season, the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} produced the highest yield (1269 kg ha^{-1}) followed by sole application of C_{150} g hill^{-1} treatment (1222 kg ha^{-1}) representing 126 % and 117 % over the control, respectively, (Table 4.18). In the 2014 cropping season, the combined application of C_{300} g hill^{-1} and 50 % N P_{RR} treatment gave the highest yield of 1917 kg ha^{-1} followed by the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} (1758 kg ha^{-1}) while the control gave the lowest yield of 365 kg ha^{-1}. There was a significant difference ($P < 0.001$) among the treatments in the millet grain yield during the 2013 and 2014 cropping seasons (Table 4.18).

4.4.1.2 Millet biomass yield

The millet biomass yield for the 2013 and 2014 cropping seasons following the application of MGB-compost, N and P fertilizers are presented in Table 4.19. In the 2013 cropping season, significantly higher ($P < 0.001$) millet biomass yield of 3003 kg ha^{-1} was recorded for the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} treatment while the control treatment gave the lowest yield of 1215 kg ha^{-1}. The millet biomass yield obtained during the 2014 cropping season ranged between 1015 to 4135 kg ha^{-1}. The control treatment gave the lowest biomass yield while the combined application of C_{300} g hill^{-1} and 50 % N P_{RR} treatment gave the highest.

There was a significant interaction ($P = 0.02$) between year and treatments applied (Appendix 7). Generally, it was observed that millet biomass yield obtained in 2014 cropping season was relatively higher than that obtained during the 2013 cropping season.

Table 4.18. Effect of MGB-compost, N and P fertilizers on millet grain yield

Treatments	Grain yield (kg ha^{-1})	Increase over control (%)	Grain yield (kg ha^{-1})	Increase over control (%)
	2013		2014	
$C_0 + N_0 P_{0RR}$	562	-	365	-
C_0 + 50% N P_{RR}	481	-14	784	115
C_0 + 100% N P_{RR}	1208	115	1131	210

C_{150} + N_0 P_{0RR}	1222	117	1082	196
C_{150} + 50% N P_{RR}	1077	92	1022	180
C_{150} + 100% N P_{RR}	1141	103	1588	335
C_{300} + N_0 P_{0RR}	877	56	1170	221
C_{300} + 50% N P_{RR}	1134	102	1917	425
C_{300} + 100% N P_{RR}	1269	126	1758	382
Probability (P)	< 0.001	-	< 0.001	-
L.s.d (5%)	269	-	401	-
CV (%)	18.5	-	22.9	-

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied

Table 4.19. Effect of MGB-compost, N and P fertilizers on millet biomass yield

Treatments	Biomass yield (kg ha^{-1})	Increase over control (%)	Biomass yield (kg ha^{-1})	Increase over control (%)
	2013		2014	
C_0 + N_0 P_{0RR}	1215	-	1015	-
C_0 + 50% N P_{RR}	1473	21	2735	169
C_0 + 100% N P_{RR}	2598	114	2989	194

$C_{150} + N_0 P_{0RR}$	2063	70	3073	203
C_{150} + 50% N P_{RR}	1874	54	2341	131
C_{150} + 100% N P_{RR}	2036	68	3501	245
$C_{300} + N_0 P_{0RR}$	1874	54	2767	173
C_{300} + 50% N P_{RR}	1988	64	4135	307
C_{300} + 100% N P_{RR}	3003	147	3172	213
Probability (P)	< 0.001	-	0.002	-
L.s.d (5%)	544	-	1192	-
CV (%)	18.5	-	28.6	-

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied

4.4.1.3 Cowpea grain yield

The results of the study indicated that cowpea grain yield of the treatments were significantly higher (P < 0.001) than the control during the two cropping seasons (Table 4.20). The highest grain yield was recorded by the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} and this was 397 and 722 % more than that of the control treatment in the 2013 and 2014 cropping seasons, respectively. Appendix 7 shows a significant interaction between year and treatments applied (P = 0.009) on cowpea grain yield. Generally, it was observed that cowpea grain yield obtained in 2014 cropping season was higher than that obtained in 2013 cropping season only in the treatment with combined application of C_{300} g hill^{-1} and 50 % N P_{RR} or 100 % N

P_{RR}. Pest attack was observed at cowpea flowering during 2014 cropping season and *Deltacal* pesticide was used to control the pest.

Table 4.20. Effect of MGB-compost, N and P fertilizers on cowpea grain yield

Treatments	Grain yield (kg ha^{-1})	Increase over control (%)	Grain yield (kg ha^{-1})	Increase over control (%)
	2013		2014	
$C_0 + N_0 P_{0RR}$	317	-	230	-
C_0 + 50% N P_{RR}	980	209	655	185
C_0 + 100% N P_{RR}	756	138	863	275
$C_{150} + N_0 P_{0RR}$	980	209	803	249
C_{150} + 50% N P_{RR}	1196	277	753	227
C_{150} + 100% N P_{RR}	1533	384	1413	514
$C_{300} + N_0 P_{0RR}$	1188	275	938	308
C_{300} + 50% N P_{RR}	1200	279	1879	717
C_{300} + 100% N P_{RR}	1574	397	1891	722
Probability (P)	< 0.001	-	< 0.001	-
L.s.d (5%)	423	-	419	-
CV (%)	26.8	-	27.4	-

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied

4.4.1.4 Cowpea haulm yield

Table 4.21 shows cowpea haulm yield of the treatments obtained at harvest. The highest cowpea haulm yield of 1921 kg ha^{-1} was obtained from the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} during the 2013 cropping season. The combined application of C_{300} g hill^{-1} and 50 % N P_{RR} gave the highest (2686 kg ha^{-1}) cowpea haulm yield during the 2014 cropping season, representing 784 % increase over that of the control. Appendix 7 shows a significant interaction between year and treatments applied (P = 0.002) on cowpea haulm yield.

Table 4.21. Effect of MGB-compost, N and P fertilizers on cowpea haulm yield

Treatments	Haulms yield (kg ha^{-1})	Increased over control (%)	ıulms yield (kg ha^{-1})	Increased over control (%)
	2013		2014	
C_0 + N_0 P_{0RR}	466	-	304	-
C_0 + 50% N P_{RR}	1005	116	928	205
C_0 + 100% N P_{RR}	862	85	917	202
C_{150} + N_0 P_{0RR}	1050	125	921	203
C_{150} + 50% N P_{RR}	1346	189	1452	378
C_{150} + 100% N P_{RR}	1439	209	1803	493
C_{300} + N_0 P_{0RR}	1240	166	1170	285
C_{300} + 50% N P_{RR}	1183	154	2686	784
C_{300} + 100% N P_{RR}	1921	312	2568	745

Probability (P)	< 0.001	-	< 0.001	-
L.s.d (5%)	373	-	415	-
CV (%)	21.9	-	20.1	-

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied

4.4.1.5 Millet and cowpea harvest indices

The combined application of C_{300} g hill^{-1} and 50 % N P_{RR} treatment gave the highest (53.01 %) millet harvest index followed by the combined application of C_{150} g hill^{-1} and 100 % N P_{RR} treatment (52.75 %), while the sole application of 50 % N P_{RR} treatment gave the lowest value of 37.29 % (Table 4.22).

The highest cowpea harvest index of 94.5 % was obtained from plots receiving the combined application of C_{150} g hill^{-1} and 100 % N P_{RR} treatment followed by that of the sole application of 100% N P_{RR} treatment (92.4 %) while the control recorded the least value of 74.60 %. Significant ($P < 0.001$) differences were observed among the treatments on millet and cowpea harvest indices. It was also observed that a significant interaction ($P < 0.001$) between year and treatments for millet and cowpea harvest index (Table 4.23).

4.4.1.6 Sustainability yield indices and agronomic efficiency of millet and cowpea

The highest sustainability yield index for millet was obtained from the combined application of C_{300} g hill^{-1} and 50 % N $P_{RR,}$ while the least value of 0.03 was recorded for the control treatment. Significant ($P < 0.001$) differences were observed between the treatments. It was also observed that significant ($P < 0.001$) interaction occurred among the treatments and year for millet sustainability yield index (Table 4.22). The combined application of C_{300} g hill^{-1} and 100 % N P_{RR} gave the highest cowpea yield sustainability index of 0.69 followed by the combined application of C_{300} g hill^{-1} and 50 % N P_{RR} with a value of 0.66 (Table 4.23). Among the various treatments, sole application of C_{150} g hill^{-1} gave the highest agronomic efficiency for millet grain and stover (Table 4.22). The highest value of 34.62 kg ha^{-1} for cowpea grain agronomic efficiency was obtained under plots treated with sole C_{150} g hill^{-1}. For cowpea haulm production, the best treatment in terms of agronomic efficiency was C_{300} g hill^{-1} and 50 % N P_{RR} with a value of 38.27 kg ha^{-1} (Table 4.23).

Table 4.22. Effect of MGB-compost, N and P fertilizers on millet harvest index, sustainability yield index and agronomic efficiency

Treatments	Harvest index (%)	Sustainability yield index	Agronomic efficiency (kg ha^{-1})	
			Grain	Stover
C_0 + N_0 P_{0RR}	42.05	0.03	-	-
C_0 + 50% N P_{RR}	37.29	0.25	9.27	20.32
C_0 + 100% N P_{RR}	42.38	0.39	14.93	26.68
C_{150} + N_0 P_{0RR}	49.12	0.38	31.88	40.70
C_{150} + 50% N P_{RR}	51.02	0.33	14.90	24.50
C_{150} + 100% N P_{RR}	52.75	0.5	15.12	22.72
C_{300} + N_0 P_{0RR}	45.48	0.38	29.58	38.53
C_{300} + 50% N P_{RR}	53.01	0.59	22.92	32.57
C_{300} + 100% N P_{RR}	50.65	0.57	18.10	24.78

Year (Prob.)	0.002	0.030	< 0.001	< 0.001
Treatment (Prob.)	< 0.001	< 0.001	< 0.001	< 0.001
Year *x* treatment (Prob.)	< 0.001	< 0.001	< 0.001	< 0.001
L.s.d-treatment (5%)	5.10	0.08	3.07	3.97
CV (%)	10.8	20.8	15.0	13.2

Prob., probability; C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied, Prob., probability.

Table 4.23. Effect of MGB-compost, N and P fertilizers on cowpea harvest index, sustainability yield index and agronomic efficiency

Treatments	Harvest index (%)	Sustainability yield index	Agronomic efficiency (kg ha^{-1})	
			Grain	Haulm
C_0 + N_0 P_{0RR}	74.6	0.01	-	-
C_0 + 50% N P_{RR}	83.4	0.28	32.35	26.93
C_0 + 100% N P_{RR}	92.4	0.28	9.97	11.62
C_{150} + N_0 P_{0RR}	91.6	0.32	34.62	37.65
C_{150} + 50% N P_{RR}	73.2	0.36	21.48	33.82
C_{150} + 100% N P_{RR}	94.5	0.63	21.68	25.17
C_{300} + N_0 P_{0RR}	90.1	0.41	29.93	32.50
C_{300} + 50% N P_{RR}	89.6	0.66	29.85	38.27
C_{300} + 100% N P_{RR}	79.6	0.69	23.10	31.70
Year (Prob.)	< 0.001	0.189	0.459	< 0.001
Treatment (Prob.)	< 0.001	< 0.001	< 0.001	< 0.001
Year *x* treatment (Prob.)	< 0.001	< 0.001	< 0.001	< 0.001
L.s.d-treatment (5%)	10.20	0.08	3.20	3.65
CV (%)	13.0	19.8	12.1	11.7

Prob., probability; C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied; Prob., probability.

4.4.2 Discussion

4.4.2.1 Millet and cowpea yield

The results of this study showed that the treatments were significantly superior over the control. Ayoola (2006) reported that crop yields were usually least in control plots because crops had to use the limited nutrients that the soil could supply without any external inputs. The combined use of MGB-compost and N and P fertilizers in general gave the highest millet and cowpea grain yields at the end of study period.

Other workers have demonstrated similar results with combined use of organic and inorganic sources of nutrients (Gitari and Friesen, 2004; Ayoola and Makinde, 2007; Demelash *et al.*, 2014). Generally, it was observed that millet biomass and cowpea yield obtained in 2014 cropping season was significantly higher than that obtained during the 2013 cropping season (Appendix 7). This can be explained by the fact that millet and cowpea growth in 2014 benefited from the residual effect of the precious treatments applied. This result indicates that smallholder farmers who cannot apply the recommendation rate of 5 t ha^{-1} (CNEV, 2012) of organic fertilizer every year could improve millet and cowpea productivity by applying MGB-compost at 150 or 300 g $hill^{-1}$ every year in combination with or without mineral fertilizer. The results of this study are in agreement with others reported by Ouédraogo *et al.* (2001), Sarwar *et al.* (2007) and Demelash *et al.* (2014) applying compost and mineral fertilizer on sorghum, rice/wheat and wheat, respectively.

The addition of MGB-compost improved organic carbon content of the soil and also the readily available nutrients from the N and P fertilizers applied (Table 4.9). The improvement of crops yield from combined application of compost and mineral fertilizer could be related to better crop development, due to the readily available nutrients from the mineral fertilizer sources and the improved nutrient availability from the compost (Seran *et al.*, 2010; Suge *et al.*, 2011; Badar *et al.*, 2015). Millet and cowpea grain yield obtained from the MGB-compost applied at 300 g $hill^{-1}$ treatment was relatively high when it was applied in addition to half recommended rate (50 %) of N and P fertilizers. Results from this study have also shown that, the combination of MGB-compost and N and P fertilizers could help to reduce 50 % of mineral fertilizer requirement for achieving yield comparable with those obtained from full application of mineral fertilizer at recommended rates. Palm *et al.* (1997b) reported the possibility of saving 50 % dose of inorganic fertilizer through integrated use of mineral fertilizer and organic material. Furthermore, the combined use of organic fertilizer with inorganic fertilizer improves inorganic fertilizer use efficiency and thus reduces the amount of inorganic fertilizer required (Tilahun-Tadesse *et al.*, 2013).

The high millet grain yield recorded for the sole application of N and P fertilizers at 100 % RR treatment during the 2013 cropping season could be attributed to the nutrients which were readily available for use by the plants. The low millet yield recorded from the sole application of the MGB-compost at 300 g $hill^{-1}$ was not expected because MGB-compost releases more nutrients and conserve soil moisture content at millet flowering (Figures 4.3 to 4.6 and Table 4.13). The result could probably be due to low inherent soil fertility of the experimental plot. However, high cowpea grain yield was obtained by applying MGB-compost at 300 g $hill^{-1}$. This result could probably be explained by the fact that nutrient release from this treatment was sufficient to sustain cowpea yield (Table 4.20). Earlier studies have shown that adding organic amendments to soil improves the soil physical and biological conditions by creating a more favorable environment for root growth and nutrient availability, increased plant growth and dry matter production (Kaplan *et al.*, 2007).

Millet and cowpea grain yield obtained between sole application of MGB-compost at 150 g hill^{-1} and 300 g hill^{-1} during the 2013 and 2014 cropping seasons was not averagely significantly different (Tables 4.18 and 4.20). Fraser *et al.* (2006) explained that there is an economically efficient level of manure application beyond which increased rates do not improve yields. Among the treatments, combined application of MGB-compost and N and P fertilizers produced the highest yield of cowpea. The highest cowpea grain yield of 1891 kg ha^{-1} obtained in the study during 2014 cropping season was more than that (1269 kg ha^{-1}) reported by Saidou *et al.* (2014), working on compost in combination with mineral fertilizer in Niger. Omae *et al.* (2014) demonstrated that in the Sahel, the application of manure and mineral fertilizer improved cowpea and millet biomass yield sustainability from 27 - 147 % over that of control.

4.4.2.2 Harvest index, sustainability yield indices and agronomic efficiency of millet and cowpea

The value of harvest index and its sustainability are key determinants of crop yield (Echarte and Andrade, 2003). The treatments with combined application of MGBcompost with or without N and P fertilizers recorded relatively higher millet and cowpea harvest indices at the end of study period. The values obtained for millet harvest index corroborate the findings of Hay and Gilbert (2001) who worked on maize productivity. Low grain crop harvest index could be attributed to late sowing, imperfect sowing methods, low plant population, poor plant protection, and nonavailability of water at critical crop growth stages (Ahmad *et al.*, 2007). The high harvest index of cowpea found in this study could be explained by the higher planting density of cowpea relative to millet and the frequency of cowpea grain harvesting. The duration of grain harvesting influences leaves production by increasing defoliation which consequently decreases haulm yield.

The sustainability yield index data of millet and cowpea from this study were relatively more stable under combined use of MGB-compost and N and P fertilizers treatment regimes relative to sole MGB-compost or N and P fertilizers application (Table 4.22 and 4.23). Vittal *et al.* (2002) reported that any practice that gives sustainability yield index greater than 0.66 is considered as a recommendable component for production and sustainability yield index of 0.50 to 0.65 is considered as highly promising. The treatments of combined application of MGB-compost at 300 g hill^{-1} and N and P fertilizer at 50 % or 100 % RR were recommendable on cowpea production. However, the treatments of combined application of MGBcompost at 300 g hill^{-1} and N and P fertilizer at 50 % or 100 % RR were highly promising on millet production in Niger. The result from this work was however in contrast with that of Bhattacharyya *et al.* (2008) who reported that a soybean-wheat system was more stable under farmyard manure compared to other practices of sole or combined application of organic and inorganic fertilizers. Combined application of MGB-compost and N and P fertilizers promoted millet and cowpea yield and agronomic efficiency (Table 4.18, 4.20, 4.22 and 4.23). Shah *et al.* (2009) observed that agronomic efficiency was higher in treatments where 25 % N was supplied from poultry manure and 75 % from mineral fertilizer. In this present study, the highest agronomic efficiency of millet and cowpea were observed in sole application of MGB-compost at 150 g hill^{-1}. This result could be explained by the high yield given by this treatment, irrespective of the quantity of nutrient applied. The improvement of agronomic efficiency depends on the decomposition and nutrients release of organic materials applied (Vanlauwe *et al.*, 2011). Generally, in the 2014 cropping season, the yields of millet and cowpea were significantly higher in comparison to the previous year (2013). This finding shows that the continuous application of MGB-compost with or without N and P fertilizers on millet and cowpea combined with good rainfall can contribute to achieving high yield sustainability in the semiarid zone of Niger.

4.5 Economic benefit of MGB-compost, nitrogen and phosphorus fertilizers application under millet/cowpea based cropping systems in Niger

4.5.1 Results

4.5.1.1 Added benefits derived from integrated application of MGB-compost, N and P fertilizers on millet and cowpea grain yield

The added benefits from combined application of MGB-compost and N and P fertilizers on millet and cowpea grain yield are as shown in Figure 4.16.

The application of MGB-compost and N and P fertilizers resulted in a negative added benefit ranging from -216 to -494 kg ha^{-1} and -68 to -463 kg ha^{-1} on millet and cowpea grain yield, respectively. A positive added benefit for grain yield was obtained only when the combined application of C_{300} g $hill^{-1}$ and 50 % N P_{RR} treatment was applied on millet and when the combined application of C_{150} g $hill^{-1}$ and 100 % N P_{RR} and C_{300} g $hill^{-1}$ and 100 % N P_{RR} were applied to cowpea plots.

4.5.1.2 Returns on investment of combined application of MGB-compost and N and P fertilizers

Tables 4.24 and 4.25 present the returns on investment of combined use of MGBcompost and N and P fertilizers in millet and cowpea production. For millet production, the sole application of C_{150} g hill^{-1} gave an incremental income of US$ 276, representing 99 % of the relative increase in income. This was followed by C_{300} g hill^{-1} and 50 % N P_{RR} which gave the incremental income of US$ 268 representing 96.3 % of the relative increase in income (Table 4.24). The application of MGBcompost with or without N and P fertilizers, except C_{150} g hill^{-1}, accrued net negative returns on millet grain yield as the VCR estimates were less than 1 (Table 4.24). The most economically attractive nutrient management option on millet in this study was therefore the sole application of MGB-compost at 150 g hill^{-1}.

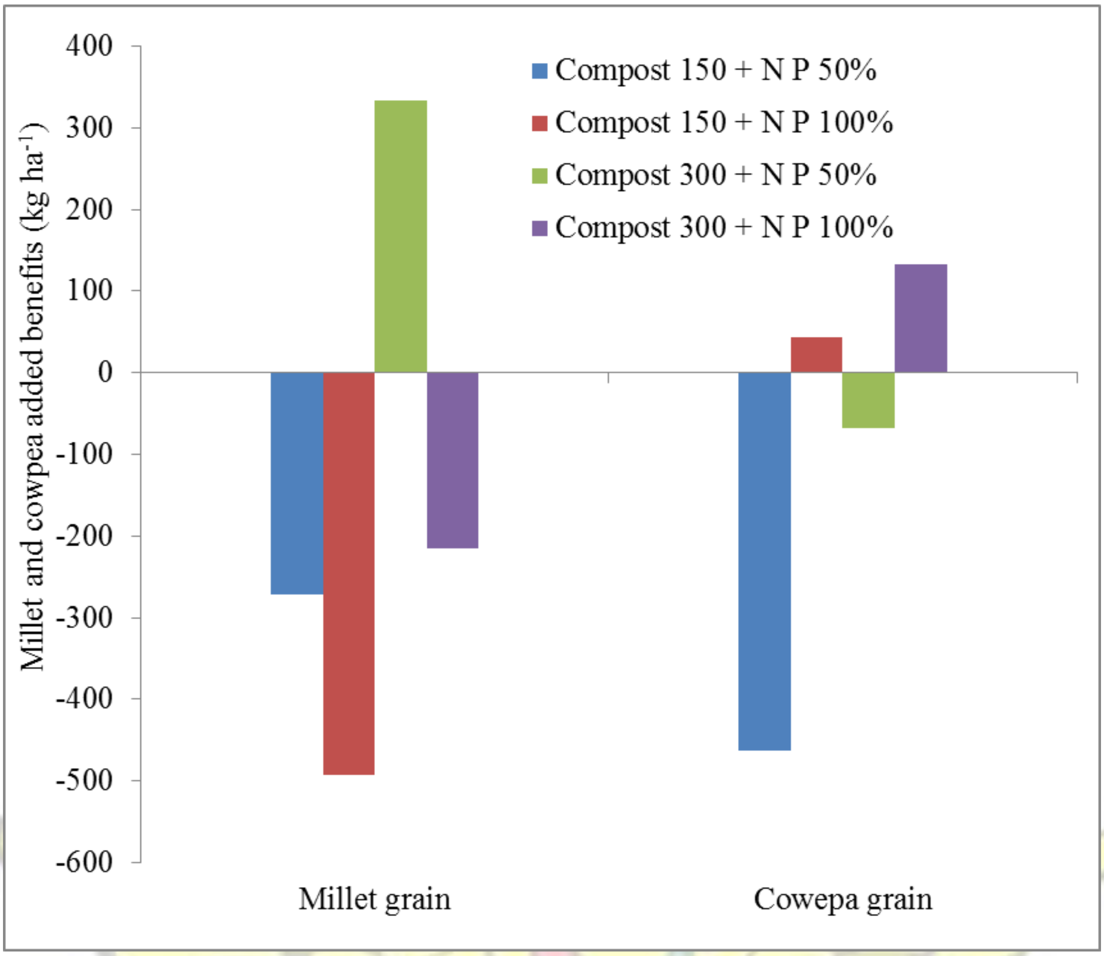


Figure 4.16. Added benefits from MGB-compost and N and P fertilizers application

Table 4.24. Financial analysis of the use of MGB-compost, N and P fertilizers on millet production

Treatments	Grain yield	Gross income	Variable cost	Net income	Incr. income	VCR	RII
	(kg ha^{-1})	(US$)	(US$)	(US$)	(US$)	-	%
$C_0 + N_0 P_{0RR}$	464	278	-	278	-	-	-
C_0 + 50% N P_{RR}	916	550	95	455	176	1.9	63.3
C_0 + 100% N P_{RR}	1169	701	190	512	233	1.2	83.8
$C_{150} + N_0 P_{0RR}$	1152	691	137	554	276	2.0	99.0

C_{150} + 50% N P_{RR}	1050	630	232	398	120	0.5	42.9
C_{150} + 100% N P_{RR}	1365	819	327	492	214	0.7	76.8
C_{300} + N_0 P_{0RR}	1143	686	274	411	133	0.5	47.8
C_{300} + 50% N P_{RR}	1526	916	369	546	268	0.7	96.3
C_{300} + 100% N P_{RR}	1514	908	464	444	166	0.4	59.6

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied; Incr. income = incremental income; VCR = value cost ratio; RII = relative increase in income

For cowpea production, the combined application of C_{300} g hill^{-1} and 100 % N P_{RR} gave the highest incremental income (US$ 1186), representing 362.1 % of relative increase in income. However, the lowest incremental income of US$ 353 was observed in the sole application of 100 % N P_{RR} representing 107.8 % relative increase in income (Table 4.25). The application of MGB-compost with or without N and P fertilizers accrued positive returns on cowpea production during the study. The VCR of MGB-compost with or without N and P fertilizers was estimated to range from 1.2 to 4.4 (Table 4.25). The most economically attractive nutrient management option for cowpea production in this study was also the sole application of MGBcompost at 150 g hill^{-1}.

Table 4.25. Financial analysis of the use of MGB-compost, N and P fertilizers on cowpea production

Treatments	Grain yield	Gross income	Variable cost	Net income	Incr. income	VCR	RII
	(kg ha^{-1})	(US$)	(US$)	(US$)	(US$)	-	%

$C_0 + N_0 P_{0RR}$	273	328	-	328	-	-	-
C_0 + 50% N P_{RR}	818	982	146	836	508	3.5	155.2
C_0 + 100% N P_{RR}	810	972	291	681	353	1.2	107.8
$C_{150} + N_0 P_{0RR}$	892	1070	137	933	606	4.4	184.9
C_{150} + 50% N P_{RR}	974	1169	283	886	558	2.0	170.4
C_{150} + 100% N P_{RR}	1473	1768	428	1339	1012	2.4	308.8
$C_{300} + N_0 P_{0RR}$	1063	1276	274	1001	674	2.5	205.6
C_{300} + 50% N P_{RR}	1540	1848	420	1428	1100	2.6	335.9
C_{300} + 100% NP_{RR}	1733	2080	566	1514	1186	2.1	362.1

C_0, C_{150} and C_{300} g, compost applied by hill; 0%, 50% and 100%, recommended rate (RR) of nitrogen and phosphorus fertilizers applied; Incr. income = incremental income; VCR = value cost ratio; RII = relative increase in income

4.5.2 Discussion

4.5.2.1 Effect of combined application of MGB-compost and N and P fertilizers on millet and cowpea grain yield

The negative added benefit of combined application MGB-compost and N and P fertilizers in the present study could be explained by the higher response of millet and cowpea from the sole application of MGB-compost or N and P fertilizers treatments. The result was strengthened by the improved distribution of rainfall during the two years of the study (Appendix 5) and good nutrient release pattern of MGB-compost. Ouédraogo *et al.* (2007) reported an added benefit of -101 kg ha^{-1} following the combined application of sheep manure and urea and attributed the negative effect to low nutrient utilization efficiency induced by moisture stress during crop grain filling. Mucheru *et al.* (2004) also found negative added benefits in the order of -150 to -250 kg ha^{-1} following the combined application of 30 kg N ha^{-1} of *Leucaena leucocephala* and 30 kg N ha^{-1} of mineral fertilizer. The negative effect of *L. leucocephala* biomass and mineral fertilizer observed by these authors was attributed to the high polyphenol content of the organic manure and its adverse effect on decomposition rate and N release. The negative added benefit of this study meant that the grain yield obtained from the combined MGB-compost and N and P fertilizers treatments (Figure 4.16) could not sufficiently compensate for the investment made. A similar result was reported by Zougmoré *et al.* (2005) working on water conservation measures combined with nutrient management.

However, the positive interaction between MGB-compost and N and P fertilizers on millet and cowpea as shown by the added benefits of 333 and ranging from 44 to 133 kg ha^{-1}, respectively during the study period were consistent with the additivity or synergism between organic and mineral fertilizers as reported by Vanlauwe *et al.* (2001b); Iwuafor *et al.* (2001); Gentile *et al.* (2008); Sanginga and Woomer (2009); Amusan *et al.* (2011) and Opoku (2011). For example, Sanginga and Woomer (2009) cited the supply of all essential nutrients in suitable quantities and proportions as the possible mechanism underlying the observed synergism. These authors showed that the mineral fertilizer supplied adequate levels of macro nutrients, while micro nutrients absent in the mineral fertilizer were supplied by the organic material sources. Certainly, the improvement in the synchrony between nutrient availability and crop demand resulting from the immediate release of nutrients from the mineral fertilizer and delayed release from the organic material (Palm *et al.*, 1997a; Jones *et al.*, 1997; Vanlauwe *et al.*, 2001b) cannot be ruled out. The positive effect of the treatments on soil nutrients and moisture content from the study could also contribute to this explanation.

Soil nutrient retention, nutrient availability and moisture retention as suggested by Vanlauwe *et al.* (2001a) could have been improved, leading to higher grain yields. In a study to appraise the effect of combined use of cattle manure and ammonium nitrate on maize yield, Nhamo (2001) found added benefits ranging from 663 to 1188 kg grain ha^{-1} and attributed the synergistic effect to supply of cations by manure to ameliorate the low cation content of the soil. An important issue is the economic benefit which depends mainly on the yield level of treatments and crops. Furthermore, adopting a technology by farmers is only effective if they perceive a clear return on their direct investment cost (Dudal, 2002; Zougmoré *et al.*, 2005)

4.5.2.2 Cost of and returns on combined use of MGB-compost and N and P fertilizers on millet and cowpea production

The results from this study showed that returns on investment accruing from the application of MGB-compost and N and P fertilizers were negative (VCR < 1) on millet production except in sole application N and P fertilizers and MGB-compost applied at 150 g hill^{-1}. This could be explained by the low potential grain yield of millet varieties used and its low grain selling prize in Niger. Bielders and Gérard (2015) reported that the minimum yield increase required to compensate for the financial investment (VCR = 1) depends on market price of millet grain. Consequently, the yields obtained from sole application of MGB-compost at 150 g hill^{-1} and sole application of N and P fertilizers on millet could compensate the investment made (Table 4.24). Maman and Mason (2013) showed that the application of poultry manure and mineral fertilizer on millet in Niger yielded VCR ranging from 6.52 to 7.18. These higher VCRs were obtained only when farmers spent less on acquisition of poultry manure and mineral fertilizer. The positive returns obtained from the sole application of N and P fertilizers on millet and cowpea in this study confirm the role of mineral fertilizer as a key entry point for increasing crop productivity. This finding corroborates with observation made by Sanginga and Woomer (2009) and Opoku (2011). In general, the low profitability of mineral fertilizer use in West Africa has been attributed to poor crop response (Dembélé and

Savadogo, 1996) and unfavorable fertilizer to cereals price ratios (Gerner and Harris, 1993).

Jama *et al.* (1997) and Mutuo *et al.* (2000) indicated that organic materials have high labour costs. However, in rural areas of Niger, farmers use self labour for making compost. Accordingly, the nutrient management option with optimum returns on nutrient inputs was the sole application of MGB-compost at 150 g hill^{-1} on millet and cowpea. The VCRs of C_{300} g hill^{-1} and 50 % N P_{RR} (0.7 for millet and 2.6 for cowpea) were superior to the VCRs of C_{300} g hill^{-1} and 100 % N P_{RR} (0.4 for millet and 2.1 for cowpea) during the study period. In economic terms, farmers could make 50 % saving on fertilizer cost for adopting the practice of combined application of MGB-compost at 300 g hill^{-1} and N and P fertilizers at 50 % RR. This observation is in agreement with findings of Yaduvanshi (2003), Kiani *et al.* (2005) and MucheruMuna *et al.* (2007). Also, Khaliq *et al.* (2006) reported that in addition to economic and monetary benefits, a 50 % save in mineral fertilizer would have a significant effect on the environment and human health.

CHAPTER FIVE

5.0 Summary, conclusions and recommendations

5.1 Summary

Application of inorganic and organic fertilizers to soil supply nutrients and also helps to build soil organic matter over the long term. Knowledge of the nutrient contents, decomposition and mineralization patterns of organic amendments, and their effects on crop productivity and soil properties, are important to planning their use in soil fertility management. The aim of this study was to evaluate management practices that can improve the fertilizer value of millet glume through composting with goat manure and determine the contribution of MGB-compost, phosphorus and nitrogen fertilizers on soil fertility and millet/cowpea productivity in Niger.

i. This study has shown that millet glume has a potential as an organic amendment in Niger.

ii. MGB-compost decomposed faster than millet glume. The half-life (t_{50}) was 12.38 weeks and 4.65 weeks for millet glume and MGB-compost, respectively. The peaks of N, P, Ca and Mg released from MGB-compost were observed on the 14^{th} day of incubation under laboratory conditions. iii. Application of MGB-compost during the field study improved soil chemical, moisture content and microbial biomass C, N, P properties. Total nitrogen, available P, organic carbon and exchangeable bases of MGB-compost and N and P fertilizers of amended plots were significantly higher than those of the control plot. The moisture content and microbial biomass C, N and P contents of MGB-compost amended plots were significantly higher than those of the control and sole N and P fertilizers plots.

iv. Generally, combined use of MGB-compost and N and P fertilizers gave the highest millet and cowpea grain yield relative to the control.

v. The use of MGB-compost and N and P fertilizers was not economically viable for millet production except where MGB-compost was applied at 150 g hill^{-1} (VCR = 2.0). However, the sole application of MGB-compost or in combination with N and P fertilizers gave the highest VCRs (2.0 to 4.4) for cowpea production.

5.2 Conclusions

On the basis of the outcomes of this study, the following conclusions can be drawn:

a) composted millet glume could serve as an alternative organic material for improving soil fertility and millet grain yield in semi-arid zone of Niger,
b) composting millet glume enhanced its decomposition and nutrients release,
c) application of MGB-compost with or without N and P fertilizers increased soil nutrients availability and improved soil microbial biomass C, N and P,
d) use of MGB-compost and N and P fertilizers significantly improved millet and cowpea grain and biomass yields,
e) use of MGB-compost and N and P fertilizers was not economically viable for millet production. However, the application of sole MGB-compost or in combination with N and P fertilizers was economically profitable for cowpea production.

5.3 Recommendations

The recommendations arising out of the study are:

i. the optimal nutrient release (nitrogen, phosphorus, potassium) from MGB-compost occurred at 9 weeks of decomposition. A further study is therefore recommended to synchronize nutrients release from MGBcompost and nutrients demand of millet and cowpea,

ii. improving low quality organic material such as millet glume through composting requires additional high quality material. It is therefore recommended that other sources of organic materials including legume residues should be explored for increasing further the nutritive value of millet glume,

iii. the practice of composting millet glume should be promoted by the ministry of Agriculture because of the relatively cheaper cost and attendant economic benefit of the practice.

REFERENCES

Abdel-Rahman, G. (2009). Impact of compost on soil properties and crop productivity in the Sahel North Burkina Faso. *American-Eurasian Journal of Agricultural and Environmental Sciences* 6: 220-226.

Adamou, A., Bationo, A., Tabo, R. and Koala, S. (2007). Improving soil fertility through the use of organic and inorganic plant nutrient and crop rotation in

Niger. pp. 589-598. In A. Batiano, B. Waswa, J. Kihira and J. Kimetu (eds.). *Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities*. Springer, Netherlands.

Adebayo, K. and Ajayi, O. (2001). Factors determining the practice of crop livestock integration in the derived savanna and rain forest zones of Nigeria. *ASSET: An International Journal (Series A)* 1(1): 91-100.

Afomasse, D., Arouna, A. and Adegbola, P. (2004). Facteurs socio-économiques déterminant l'adoption des technologies de gestion de la fertilité des sols par les différents types d'exploitations agricoles des régions centre et nord du Benin. Communication à la Première Edition de l'Atelier Scientifique National. 18 pages.

Ahmad, R., Hassan, B. and Jabran, K. (2007). Improving crop harvest index. Ramazan 18, 1428. Dawn Group of Newspapers. http://www. DAWN.com. Accessed Feb. 2015.

Albiach, R., Canet, R., Pomares, F. and Ingelmo, F. (2000). Microbial biomass content and enzymatic activities after the application of organic amendments to a horticultural soil. *Bioresource Technology* 75(1): 43-48.

Alhamd, L., Arakaki, S. and Hagihara, A. (2004). Decomposition of leaf litter of four tree species in a subtropical evergreen broad-leaved forest, Okinawa Island, Japan. *Forest Ecology and Management* 202(1): 1-11.

Amba, A., Agbo, E., Voncir, N. and Oyawoye, M. (2011). Effect of phosphorus fertilizer on some soil chemical properties and nitrogen fixation of legumes at Bauchi. *Continental Journal* of *Agricultural Science* 5(1): 39-44.

Amoukou, I., Yamba, B., Marichatou, H. and Yayé, A. D. (2007). Vulnérabilité et innovations paysannes: l‟expérience d‟Aguié au Niger. Louvain-la-Neuve, Belgique, Presses universitaires de Louvain, 114 pages.

Amusan, A., Adetunji, M., Azeez, J. and Bodunde, J. (2011). Effect of the integrated use of legume residue, poultry manure and inorganic fertilizer on maize yield, nutrient uptake and soil properties. *Nutrient Cycling in Agroecosystems* 90(3): 321-330.

Anderson, J. M. and Ingram, J. S. I. (1993). Tropical Soil Biology and Fertility. A Handbook of methods. pp. 36-40.

Anderson, J. M. and Ingram, J. S. I. (1998). Tropical soil biology and fertility. A Handbook of methods. CAB International, Wallingford, UK. 221 pp.

Anderson, T.-H. and Domsch, K. H. (1989). Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biology and Biochemistry* 21(4): 471-479.

Arif, M., Jalal, F., Jan, M. T., Muhammad, D. and Quilliam, R. (2015). Incorporation of biochar and legumes into the summer gap: improving productivity of cereal-based cropping systems in Pakistan. *Agroecology and Sustainable Food Systems* 39(4): 391-398.

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

Austin, A. T., Vivanco, L., González‐Arzac, A. and Pérez, L. I. (2014). There's no place like home? An exploration of the mechanisms behind plant litter–decomposer affinity in terrestrial ecosystems. *New Phytologist* 204(2): 307314.

Ayoola, O. and Makinde, E. (2007). Complementary organic and inorganic fertilizer application: influence on growth and yield of cassava/maize/melon intercrop with a relayed cowpea. *Australian Journal of Basic and Applied Sciences* 1(3): 187-192.

Ayoola, O. T. (2006). Effects of fertilizer treatments on soil chemical properties and crop yields in a cassava-based cropping system. *Journal of Applied Sciences Research* 2(12): 1112-1116.

Badar, R., Khan, M., Batool, B. and Shabbir, S. (2015). Effects of organic amendments in comparison with chemical fertilizer on cowpea growth. *International Journal of Applied Research* 1(5): 66-71.

Bange, M. P., Hammer, G. L. and Rickert, K. G. (1998). Temperature and sowing date affect the linear increase of sunflower harvest index. *Agronomy Journal* 90(3): 324-328.

Barker, A. V., Rechcigl, J. and MacKinnon, H. (1997). Composition and uses of compost. pp. 140–162. In J.E. Rechcigl and H.C. MacKinnon (eds.). *Agricultural Uses of By-products and Wastes*. American Chemical Society, Washington, DC.

Bationo, A., Lompo, F. and Koala, S. (1998). Research on nutrient flows and balances in West Africa: state-of-the-art. *Agriculture, Ecosystems and Environment* 71(1): 19-35.

Bationo, A. and Mokwunye, A. (1991). Role of manures and crop residue in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Sudanian zones of West Africa. pp. 217-225. In A. U. Mokwunye (eds.). *Alleviating soil fertility constraints to increased crop production in West Africa*. Springer, Netherlands.

Bationo, A. and Ntare, B. (2000). Rotation and nitrogen fertilizer effects on pearl millet, cowpea and groundnut yield and soil chemical properties in a sandy soil in the semi-arid tropics, West Africa. *The Journal of Agricultural Science* 134(03): 277-284.

Bayala, J., Mando, A., Teklehaimanot, Z. and Ouedraogo, S. (2005). Nutrient release from decomposing leaf mulches of karité (< i> *Vitellaria paradoxa*</i>) and néré (< i> *Parkia biglobosa*</i>) under semi-arid conditions in Burkina Faso, West Africa. *Soil Biology and Biochemistry* 37(3): 533-539.

Baziramakenga, R., Lalande, R. R. and Lalande, R. (2001). Effect of de-inking paper sludge compost application on soil chemical and biological properties. *Canadian Journal of Soil Science* 81(5): 561-575.

Bekunda, M. A., Bationo, A. and Ssali, H. (1997). Soil fertility management in Africa: A review of selected research trials. pp. 63-79. In R. J. Buresh, P. A. Sanchez and F. Calhoun (eds.). *Replenishing Soil in Africa.* SSSA Special Publication. Madison, WI. USA.

Bending, G. D., Turner, M. K., Rayns, F., Marx, M.-C. and Wood, M. (2004). Microbial and biochemical soil quality indicators and their potential for differentiating areas under contrasting agricultural management regimes. *Soil Biology and Biochemistry* 36(11): 1785-1792.

Bhattacharyya, P., Chakrabarti, K. and Chakraborty, A. (2003). Effect of MSW compost on microbiological and biochemical soil quality indicators. *Compost Science and Utilization* 11(3): 220-227.

Bhattacharyya, R., Kundu, S., Prakash, V. and Gupta, H. (2008). Sustainability under combined application of mineral and organic fertilizer in a rainfed soybean–wheat system of the Indian Himalayas. *European Journal of Agronomy* 28(1): 33-46.

Bielders, C. L. and Gérard, B. (2015). Millet response to microdose fertilization in south–western Niger: Effect of antecedent fertility management and environmental factors. *Field Crops Research* 171: 165-175.

Bilkisu, N. G. and Babatunde, M. (2015). Assessment of microbial communities Encountered in soils with organic and inorganic fertilizer in Afaka area of Kaduna state, Nigeria, *International Journal of Fisheries and Aquatic Studies*; 2(4): 01-06.

Binh, N. T., Quynh, H. T. and Shima, K. (2015). Effect of Composts Combined with Chemical N Fertilizer on Nitrogen Uptake by Italian Ryegrass and N Transformation in Soil. *Journal of Agricultural Chemistry and Environment* 4(02): 37.

Binkley, D. and Hart, S. C. (1989). The components of nitrogen availability assessments in forest soils. pp. 57-112. In B. A. Stewart (eds.). *Advances in soil science*. Springer, New York.

Bitzer, C. C. and Sims, J. T. (1988). Estimating the availability of nitrogen in poultry manure through laboratory and field studies. *Journal of Environmental Quality* 17(1): 47-54.

Black, C. A. (1965). Methods of soil analysis. Part 2. Chemical and microbialogical properties. First edition. American Society of Agronomy and Soil Science Society of America. Madison, Wisconsin, USA.

Blair, G. and Boland, O. (1978). The release of phosphorus from plant material added to soil. *Soil Research* 16(1): 101-111.

Blum, A. (2005). Drought resistance, water-use efficiency, and yield potential-are they compatible, dissonant, or mutually exclusive? *Crop and Pasture Science* 56(11): 1159-1168.

Bouajila, K. and Sanaa, M. (2011). Effects of organic amendments on soil physicochemical and biological properties. *Journal of Materials and Environmental Science* 2(S1): 485-490.

Boudsocq, S., Niboyet, A., Lata, J. C., Raynaud, X., Loeuille, N., Mathieu, J., Blouin, M., Abbadie, L. and Barot, S. (2012). Plant preference for ammonium versus nitrate: a neglected determinant of ecosystem functioning? *The American Naturalist* 180(1): 60-69.

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal* (5): 464-465.

Brady, N. C. and Weil, R. R. (2010). Elements of the Nature and Properties of Soils. Prentice-Hall: Upper Saddle River, New Jersey.

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

Brinton, W. F. (2000). Compost Quality Standards and Guidelines: An International View. New York State Association of Recyclers: Wood End Research Laboratory: 15-72.

Brockett, B. F., Prescott, C. E. and Grayston, S. J. (2012). Soil moisture is the major factor influencing microbial community structure and enzyme activities across seven biogeoclimatic zones in western Canada. *Soil Biology and Biochemistry* 44(1): 9-20.

Brookes, P. (2001). The soil microbial biomass: concept, measurement and applications in soil ecosystem research. *Microbes and Environments* 16(3): 131-140.

Brookes, P. C., Landman, A., Pruden, G. and Jenkinson, D. (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(6): 837-842.

Buerkert, A., Bationo, A. and Dossa, K. (2000). Mechanisms of residue mulchinduced cereal growth increases in West Africa. *Soil Science Society of America* 64: 346-358.

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

Buerkert, A., Piepho, H.-P. and Bationo, A. (2002). Multi-site time-trend analysis of soil fertility management effects on crop production in sub-Saharan West Africa. *Experimental Agriculture* 38(02): 163-183.

Burgess, M., Mehuys, G. and Madramootoo, C. (2002). Nitrogen dynamics of decomposing corn residue components under three tillage systems. *Soil Science Society of America Journal* 66(4): 1350-1358.

Cadisch, G. and Giller, K. E. (1997). Driven by Nature: Plant Litter Quality and Decomposition. Oxon, UK, CAB International. 409 pp.

Cai, Z., Wang, B., Xu, M., Zhang, H., He, X., Zhang, L. and Gao, S. (2015). Intensified soil acidification from chemical N fertilization and prevention by manure in an 18-year field experiment in the red soil of southern China. *Journal of Soils and Sediments* 15(2): 260-270.

Cañizales-Paredes, N., Tolon-Becerra, A., Lastra-Bravo, X. and Ruiz-Dager, F. (2012). Evaluation of the effects of soil depth on microbial activity in three agroecosystems in Venezuela. *Communications in Soil Science and Plant Analysis* 43(9): 1273-1290.

CERRA-Kollo (Centre Régional de Recherche Agronomique-Kollo) (2014). Rapport de fin d‟année. 55 pages.

Chae, Y. and Tabatabai, M. (1986). Mineralization of nitrogen in soils amended with organic wastes. *Journal of Environmental Quality* 15(2): 193-198.

Charles Gould, M. (2012). Compost increases the water holding capacity of droughty soils. http://msue.anr.msu.edu/. Accessed Aug. 2015.

Charnay, F. (2005). Compostage des déchets urbains dans les Pays en Développement. Elaboration d‟une démarche méthodologique pour une production pérenne de compost, Thèse de Doctorat, Université de Limoges, 277 pages.

Chaudhary, D., Chikara, J. and Ghosh, A. (2014). Carbon and nitrogen mineralization potential of biofuel crop (*Jatropha curcas* L.) residues in soil. *Journal of Soil Science and Plant Nutrition* 14(1): 15-30.

Chen, L., Dick, W., Streeter, J. and Hoitink, H. (1996). Ryegrass utilization of nutrients released from composted biosolids and cow manure. *Compost Science and Utilization* 4(1): 73-83.

Chesson, A., Cadisch, G. and Giller, K. (1997). Plant degradation by ruminants: parallels with litter decomposition in soils. pp. 47-66. In: G. Cadisch and K.E. Giller (eds.). *Driven by Nature:Plant Litter Quality and Decomposition.* CAB International. Wallingford, UK.

Chowdhury, M. A. H., Kouno, K., Ando, T. and Nagaoka, T. (2000). Microbial biomass, S mineralization and S uptake by African millet from soil amended with various composts. *Soil Biology and Biochemistry* 32(6): 845-852.

CIP/SDR (Comité Interministériel de Pilotage de la Stratégie de Développement Rural) (2007). Revues des efforts de développement dans le secteur agricole au Niger. 85 pages.

Clark, A. (2008). Managing cover crops profitably. Handbook Series Book 9. Published by Sustainable Agriculture Network, Beltsville, MD.

CNEV (Catalogue National des Espèces et Variétés Végétales) (2012). Ministère de l‟Agriculture, République du Niger. 207 pages.

Cobo, J., Barrios, E., Kass, D. C. L. and Thomas, R. J. (2002). Decomposition and nutrient release by green manures in a tropical hillside agroecosystem. *Plant and Soil* 240(2): 331-342.

Cooperband, L., Bollero, G. and Coale, F. (2002). Effect of poultry litter and composts on soil nitrogen and phosphorus availability and corn production. *Nutrient Cycling in Agroecosystems* 62: 185-194.

Cooperband, L. R. (2000). Ce Update - Waste III Composting: Art and Science of Organic Waste Conversion to a Valuable Soil Resource. *Laboratory Medicine* 31(5): 283-290.

Crecchio, C., Curci, M., Mininni, R., Ricciuti, P. and Ruggiero, P. (2001). Shortterm 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(5): 311-318.

De Rouw, A. and Rajot, J.-L. (2004). Soil organic matter, surface crusting and erosion in Sahelian farming systems based on manuring or fallowing. *Agriculture, Ecosystems and Environment* 104(2): 263-276.

Debosz, K., Petersen, S. O., Kure, L. K. and Ambus, P. (2002). Evaluating effects of sewage sludge and household compost on soil physical, chemical and microbiological properties. *Applied Soil Ecology* 19(3): 237-248.

Dembélé, N. N. and Savadogo, K. (1996). The need to link soil fertility management to input/output market development in West Africa: key issues. Paper presented at the International Fertilizer Development Center Seminar, Lomé, Togo, 19-22 Novembre.

Demelash, N., Bayu, W., Tesfaye, S., Ziadat, F. and Sommer, R. (2014). Current and residual effects of compost and inorganic fertilizer on wheat and soil chemical properties. *Nutrient Cycling in Agroecosystems* 100(3): 357-367.

Dent, J., Edwards-Jones, G. and McGregor, M. (1995). Simulation of ecological, social and economic factors in agricultural systems. *Agricultural Systems* 49(4): 337-351.

Diack, M., Sene, M., Badiane, A., Diatta, M. and Dick, R. (2000). Decomposition of a native shrub, *Piliostigma reticulatum*, litter in soils of semiarid Senegal. *Arid Soil Research and Rehabilitation* 14(3): 205-218.

Ding, X., Han, X., Liang, Y., Qiao, Y., Li, L. and Li, N. (2012). Changes in soil organic carbon pools after 10 years of continuous manuring combined with chemical fertilizer in a Mollisol in China. *Soil and Tillage Research* 122: 36-41.

Dommergues, Y. and Ganry, F. (1986). Biological nitrogen fixation and soil fertility maintenance. pp. 95-115. In A. U. Mokwunye and P. L. G. Vlek. *Management of nitrogen and phosphorus fertilizer in sub-Saharan Africa*, Springer, Netherlands.

Dossa, E., Khouma, M., Diedhiou, I., Sene, M., Kizito, F., Badiane, A., Samba, S. and Dick, R. (2009). Carbon, nitrogen and phosphorus mineralization potential of semi-arid Sahelian soils amended with native shrub residues. *Geoderma* 148(3): 251-260.

Dudal, R. (2002). Forty years of soil fertility work in sub-Saharan Africa. pp. 7–21. In B. Vanlauwe, J. Diels, N. Sanginga and R. Merckx (eds.). *Integrated Plant Nutrient Management in Sub-Saharan Africa.* From Concept to Practice. CAB International, New York, USA,

Dugje, I., Omoigui, L., Ekeleme, F., Kamara, A. and Ajeigbe, H. (2009). Farmers‟ guide to cowpea production in West Africa. IITA, Ibadan, Nigeria: 20 pages.

Echarte, L. and Andrade, F. H. (2003). Harvest index stability of Argentinean maize hybrids released between 1965 and 1993. *Field Crops Research* 82(1): 1-12.

Edwards, L., Burney, J., Richter, G. and MacRae, A. (2000). Evaluation of compost and straw mulching on soil-loss characteristics in erosion plots of potatoes in

Prince Edward Island, Canada. *Agriculture, Ecosystems and Environment* 81(3): 217-222.

Egelkraut, T., Kissel, D. and Cabrera, M. (2000). Effect of soil texture on nitrogen mineralized from cotton residues and compost. *Journal of Environmental Quality* 29(5): 1518-1522.

Eghball, B. (2002). Soil properties as influenced by phosphorus-and nitrogen-based manure and compost applications. *Agronomy Journal* 94(1): 128-135.

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

Eklind, Y. and Kirchmann, H. (2000). Composting and storage of organic household waste with different litter amendments. I: carbon turnover. *Bioresource Technology* 74(2): 115-124.

Eklind, Y., Salomonsson, L., Wivstad, M. and Rämert, B. (1998). Use of herbage compost as horticultural substrate and source of plant nutrients. *Biological Agriculture and Horticulture* 16(3): 269-290.

Elbl, J., Plošek, L., Kintl, A., Přichystalová, J., Záhora, J. and Hynšt, J. (2013). Effect of organic-waste compost addition on leaching of mineral nitrogen from arable land and plant production. *World Academy of Science, Engineering and Technology* 78: 2858-2863.

Esse, P., Buerkert, A., Hiernaux, P. and Assa, A. (2001). Decomposition of and nutrient release from ruminant manure on acid sandy soils in the Sahelian zone of Niger, West Africa. *Agriculture, Ecosystems and Environment* 83: 51-63.

Ezcurra, E. and Becerra, J. (1987). Experimental decomposition of litter from the Tamaulipan cloud forest: a comparison of four simple models. *Biotropica*: 19:290-296.

FAO (2005). Notions de nutrition des plantes et de fertilisation des sols, Manuel de formation, Projet Intrants. 24 pages.

FAO (2006). Republic of Tunisia. Ministry of agriculture and hydric resources. General office of agricultural production. Converting biological agriculture. DGPA/FAO/FIBL, pp. 4-33.

FAO (1988). UNESCO soil map of the world, revised legend. World Soil Resources Report 60, Rome, Italy.

Fatoma, A. M. (2015). Nutrient dynamics of decomposition water hyacinth in desert soils. MSc. Thesis, Desertification and Desert Cultivation Studies Institute University of Khartoum.

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

Fatondji, D., Martius, C., Zougmore, R., Vlek, P. L., Bielders, C. and Koala, S. (2009). Decomposition of organic amendment and nutrient release under the zai technique in the Sahel. *Nutrient Cycling in Agroecosystems* 85(3): 225239.

Fening, J., Adjei-Gyapong, T., Ewusi-Mensah, N. and Safo, E. (2010a). Manure management, quality and mineralization for sustaining smallholder livelihoods in the Upper East region of Ghana. *Journal of Science and Technology (Ghana)* 30(2).

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

Fernandez-Rivera, S., Williams, T., Hiernaux, P. and Powell, J. (1995). Faecal excretion by ruminants and manure availability for crop production in semiarid West Africa. pp. 393–409. In: J.M. Powell, S. Fernandez-Rivera, T.O. Williams and C. Renard (eds.). *Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa.* Volume 2: Technical Papers. Proceedings of an International Conference, 22–26 November 1993. International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

Fischer, D. and Glaser, B. (2012). Synergisms between compost and biochar for sustainable soil amelioration. Management of Organic Waste. INTECH Open Access Publisher. pp. 167-198.

Floquet, A., Amadji, G., Igué, M., Mongbo, R. and Dah-Dovonon, J. (2001). Le point sur les contraintes socio-économiques et agro-techniques à l'adoption des innovations de gestion de la fertilité des sols sur terre de barre : synthèse des travaux réalisés par un groupe de travail de l'initiative ERICA in Actes 2 de l'atelier scientifique Sud-Centre Bénin. Niaouli. 506-521.

Fraser, H., Fleming, R., O'Halloran, I., Van Eerd, L. and Zandstra, J. (2006). Non-Nutrient value of manure-literature review for Ontario Ministry of agriculture, food and rural affairs. College, University of Guelph, Ridge Town.

Gachengo, C. N., Vanlauwe, B. and Palm, C. A. (2004). Mineralisation patterns of selected organic materials. ACIAR proceedings. pp. 54-61.

Garcıa-Gil, J., Plaza, C., Soler-Rovira, P. and Polo, A. (2000). Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. *Soil Biology and Biochemistry* 32(13): 1907-1913.

Gebremariam, G. (2015). Growth, Yield and Yield Component of Sesame (*Sesamum indicum* L.) as Affected by Timing of Nitrogen Application. *Journal of Biology, Agriculture and Healthcare* 5(5): 165-169.

Gentile, R., Vanlauwe, B., Chivenge, P. and Six, J. (2008). Interactive effects from combining fertilizer and organic residue inputs on nitrogen transformations. *Soil Biology and Biochemistry* 40(9): 2375-2384.

Gerner, H. and Harris, G. (1993). The use and supply of fertilizer in sub-Saharan Africa. pp. 107-125. In H. Van Reuler and W.H. Prins. *The Role of Plant Nutrients for Sustainable Food Crop Production in Sub-Saharan Africa*. The Dutch Association of Fertilizer Producers (VKP).

Giller, K. E., Cadisch, G., Ehaliotis, C., Adams, E., Sakala, W. D. and Mafongoya, P. L. (1997). Building soil nitrogen capital in Africa. pp. 151192. In R. J. Buresh, P. A. Sanchez and F. Calhoun (eds.). *Replenishing Soil in Africa.* SSSA Special Publication. Madison, WI. USA.

Gitari, I. and Friesen, D. (2004). The use of organic/inorganic soil amendments for enhancing maize production in central highlands of Kenya. pp. 367 – 371. In D.K. Friesen and A.F.E. Palmer (eds.). *Integrated Approaches to Higher Maize Productivity in new Millennium*: *Proceedings of the Seventh Eastern and Southern Regional Maize Conference*, CIMMYT and KARI, Nairobi, Kenya.

Giusquiani, P., Pagliai, M., Gigliotti, G., Businelli, D. and Benetti, A. (1995). Urban waste compost: effects on physical, chemical, and biochemical soil properties. *Journal of Environmental Quality* 24(1): 175-182.

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

Golueke, C. G. (1992). Bacteriology of composting. *BioCycle* 33:55-57.

Gregorich, E., Drury, C. and Baldock, J. A. (2001). Changes in soil carbon under long-term maize in monoculture and legume-based rotation. *Canadian Journal of Soil Science* 81(1): 21-31.

Gunapala, N. and Scow, K. (1998). Dynamics of soil microbial biomass and activity in conventional and organic farming systems. *Soil Biology and Biochemistry* 30(6): 805-816.

Hafidi, M., Amir, S., Meddich, A., Jouraiphy, A., Winterton, P., El Gharous, M. and Duponnois, R. (2012). Impact of applying composted biosolids on wheat growth and yield parameters on a calcimagnesic soil in a semi-arid region. *African Journal of Biotechnology* 11(41): 9805-9815.

Hansen, M. H., Hurwitz, W. N., and Madow, W. G. (1953). Sample Survey Methods and Theory, Volume I, Methods and Applications. New York: Wiley.

Harouna, A. (2002). Etude des pratiques et stratégies paysannes de gestion de la fertilité des sols et des risques climatiques dans l'arrondissement d'Aguié (Maradi): Cas du terroir villageoises de Guidan Tanyo. Mémoire de fin d'etudes, Faculté d'Agronomie, Université Abdou Moumouni de Niamey, Niger. 57 pages.

Hartz, T., Mitchell, J. and Giannini, C. (2000). Nitrogen and carbon mineralization dynamics of manures and composts. *HortScience* 35(2): 209-212.

Hassen, A., Belguith, K., Jedidi, N., Cherif, A., Cherif, M. and Boudabous, A. (2001). Microbial characterization during composting of municipal solid waste. *Bioresource Technology* 80(3): 217-225.

Hawkes, C. V., I. F. Wren, D. J. Herman and Firestone, M. K. (2005). Plant invasion alters nitrogen cycling by modifying the soil nitrifying community. *Ecology Letters* 8: 976–985.

Hay, R. and Gilbert, R. (2001). Variation in the harvest index of tropical maize: evaluation of recent evidence from Mexico and Malawi. *Annals of Applied Biology* 138(1): 103-109.

Hayashi, K., Abdoulaye, T., Matsunaga, R. and Tobita, S. (2009). Appraisal of Local Farmers' Practices on Land Management for a Guideline of Agricultural Development in the Sahel Zone of Niger, West Africa. *Japan Agricultural Research Quarterly* 43(1): 63-69.

Haynes, R., Belyaeva, O. and Zhou, Y.-F. (2015). Particle size fractionation as a method for characterizing the nutrient content of municipal green waste used for composting. *Waste Management* 35: 48-54.

Herai, Y., Kouno, K., Hashimoto, M. and Nagaoka, T. (2006). Relationships between microbial biomass nitrogen, nitrate leaching and nitrogen uptake by corn in a compost and chemical fertilizer-amended regosol. *Soil Science and Plant Nutrition* 52(2): 186-194.

Hernando, S., Lobo, M. and Polo, A. (1989). Effect of the application of a municipal refuse compost on the physical and chemical properties of a soil. *Science of the Total Environment* 81: 589-596.

Hiernaux, P. and Ayantunde, A. (2004). The Fakara: A Semi-arid Agro-ecosystem Under Stress; Report of Research Activities; First Phase (July 2002–June 2004) of the DMP-GEF Program, International Livestock Research Institute (ILRI).

Holford, I. (1997). Soil phosphorus: its measurement, and its uptake by plants. *Australian Journal of Soil Research* 35(2): 227-240.

Huang, G., Wu, Q., Wong, J. and Nagar, B. (2006). Transformation of organic matter during co-composting of pig manure with sawdust. *Bioresource Technology* 97(15): 1834-1842.

Huang, Y. and Sun, W. (2006). Changes in topsoil organic carbon of croplands in mainland China over the last two decades. *Chinese Science Bulletin* 51(15): 1785-1803.

Hue, N. (1988). Residual effects of sewage sludge application on plant and soil profile chemical composition 1. *Communications in Soil Science and Plant Analysis* 19(14): 1633-1643.

Ibrahim, A., Abaidoo, R. C., Fatondji, D. and Opoku, A. (2015). Hill placement of manure and fertilizer micro-dosing improves yield and water use efficiency in the Sahelian low input millet-based cropping system. *Field Crops Research* 180: 29-36.

Ibrahim, M., Hassan, A., Iqbal, M. and Valeem, E. E. (2008). Response of wheat growth and yield to various levels of compost and organic manure. *Pakistan Journal of Botany* 40(5): 2135-2141.

Inbar, Y., Chen, Y. and Hadar, Y. (1989). Solid-state carbon-13 nuclear magnetic resonance and infrared spectroscopy of composted organic matter. *Soil Science Society of America Journal* 53(6): 1695-1701.

INS (Institut National de la Statistique/Niger) (2013). Présentation des Résultats Préliminaires du Quatrième Recensement General de la Population de l'Habitat du Niger. pp. 1-10.

Insam, H. and Domsch, K. (1988). Relationship between soil organic carbon and microbial biomass on chronosequences of reclamation sites. *Microbial Ecology* 15(2): 177-188.

IRD (Institut de Recherche pour le développement) (2009). Le mil aliment du futur au Sahel. *Actualité scientifique*. Fiche n°325.

Iwuafor, E., Aihou, K., Jaryum, J., Vanlauwe, B., Diels, J., Sanginga, N., Lyasse, O., Deckers, J. and Merckx, R. (2001). On-farm evaluation of the contribution of sole and mixed applications of organic matter and urea to maize grain production in the Savannah. pp. 185–197. In B. Vanlauwe, J. Diels, N. Sanginga and R. Merckx (Eds.). *Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice.* CAB International, Wallingford, UK.

Jaja, E. T. and Ibeawuch, I. I. (2015). Effect of organic and inorganic manure mixture rates on the productivity of Okra. *International Journal of Agriculture and Rural Development* 18 (1): 2085-2091.

Jama, B., Swinkels, R. A. and Buresh, R. J. (1997). Agronomic and economic evaluation of organic and inorganic sources of phosphorus in western Kenya. *Agronomy Journal* 89(4): 597-604.

Janzen, H. and Kucey, R. (1988). C, N, and S mineralization of crop residues as influenced by crop species and nutrient regime. *Plant and Soil* 106(1): 35-41.

Jenkinson, D. and Ladd, J. (1981). Microbial biomass in soil: measurement and turnover. *Soil Biochemistry* 5:415-472.

Jensen, L. S., Salo, T., Palmason, F., Breland, T. A., Henriksen, T. M., Stenberg, B., Pedersen, A., Lundström, C. and Esala, M. (2005). Influence of biochemical quality on C and N mineralisation from a broad variety of plant materials in soil. *Plant and Soil* 273(1-2): 307-326.

Johnston, A. (1986). Soil organic matter, effects on soils and crops. *Soil Use and Management* 2(3): 97-105.

Jones, R., Snapp, S., Phombeya, H., Cadisch, G. and Giller, K. (1997). Management of leguminous leaf residues to improve nutrient use efficiency in the sub-humid tropics. pp. 239-252. In: G. Cadisch, K. E. Giller (Eds.). *Driven by Nature; Plant Litter Quality and Decomposition.* CAB International, Wallingford, UK.

Juárez, M. F.-D., Waldhuber, S., Knapp, A., Partl, C., Gómez-Brandón, M. and Insam, H. (2013). Wood ash effects on chemical and microbiological properties of digestate-and manure-amended soils. *Biology and Fertility of Soils* 49(5): 575-585.

Kamukondiwa, W. and Bergström, L. (1994). Nitrate leaching in field lysimeters at an agricultural site in Zimbabwe. *Soil Use and Management* 10(3): 118124.

Kaplan, M., Kocabaş, I., Sönmez, I. and Kalkan, H. (2007). The effects of different organic manure applications on the dry weight and the essential oil quantity of sage (*Salvia fruticosa Mill*.). In International Medicinal and Aromatic Plants Conference on Culinary Herbs 826, 147-152.

Kara, Ö. and Bolat, I. (2008). Soil microbial biomass C and N changes in relation to forest conversion in the Northwestern Turkey. *Land Degradation and Development* 19(4): 421-428.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F. and Muricho, G. (2012). Plot and Household-Level Determinants of Sustainable Agricultural Practices in Rural Tanzania. Discussion Papers, Resources for the Future.

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

Khind, C. (1992). Nutrient transformations in soils amended with green manures. pp. 237-309. In B. A. Stewart (eds.). *Advances in soil science*. Springer, New York.

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

Kihara, J., Kimetu, J., Vanlauwe, B., Bationo, A., Waswa, B. and Mukalama, J. (2007). Optimising crop productivity in legume-cereal rotations through nitrogen and phosphorus management in western Kenya. pp. 493-502. In A. Batiano, B. Waswa, J. Kihira and J. Kimetu (eds.). *Advances in Integrated soil fertility management in Sub-Saharan Africa: challenges and opportunities*. Springer, Netherlands.

Kimani, S., Macharia, J., Gachengo, C., Palm, C. and Delve, R. (2004). Maize production in the central highlands of Kenya using cattle manures combined with modest amounts of mineral fertilizer. *Uganda Journal of Agricultural Sciences* 9(1): 480-490.

Kipsat, M. (2007). Socio-economics of soil conservation in Kericho district, Kenya. pp. 1001-1012. In A. Batiano, B. Waswa, J. Kihira and J. Kimetu (eds.). *Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities*. Springer, Netherlands.

Kladivko, E. and Nelson, D. (1979). Changes in soil properties from application of anaerobic sludge. *Journal of Water Pollution Control Federation*: 325-332.

Kuo, S., Ortiz-Escobar, M., Hue, N. and Hummel, R. (2004). Composting and compost utilization for agronomic and container crops. *Recent Research Developments in Environmental Biology* 1: 451-513.

Kuo, S., Sainju, U. and Jellum, E. (1997). Winter cover cropping influence on nitrogen in soil. *Soil Science Society of America Journal* 61(5): 1392-1399.

Kwabiah, A., Palm, C., Stoskopf, N. and Voroney, R. (2003). Response of soil microbial biomass dynamics to quality of plant materials with emphasis on P availability. *Soil Biology and Biochemistry* 35(2): 207-216.

Landon, J. R. (2014). Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Routledge. New York. USA.

Laryea, K., Anders, M. and Pathak, P. (1995). Long term experiments on alfisols and vertisols in the semi-arid tropics. pp. 267-292. In R. Lal and B. A. Stewart (eds.). *Soil Management: Experimental Basis for Sustainability and Environmental Quality*. CRC Press, Boca Raton, USA.

Lekasi, J. K., Ndung'u, K. W. and Kifuko, M. N. (2003). A scientific perspective on composting. pp. 65-70. In C.E.N. Savala, M.N. Omare and P.L. Woomer (eds.). *Organic Resource Management in Kenya: Perspectives and Guidelines.* The Forum for Organic Resource Management and Agricultural Technologies, Nairobi, Kenya.

Liu, P., Huang, J., Han, X., Sun, O. J. and Zhou, Z. (2006). Differential responses of litter decomposition to increased soil nutrients and water between two contrasting grassland plant species of Inner Mongolia, China. *Applied Soil Ecology* 34(2): 266-275.

Lovell, R. and Jarvis, S. (1998). Soil microbial biomass and activity in soil from different grassland management treatments stored under controlled conditions. *Soil Biology and Biochemistry* 30(14): 2077-2085.

Lupwayi, N., Clayton, G., O'Donovan, J., Harker, K., Turkington, T. and Soon, Y. (2007). Phosphorus release during decomposition of crop residues under conventional and zero tillage. *Soil and Tillage Research* 95(1): 231-239.

Lynam, J. K. and Herdt, R. W. (1989). Sense and sustainability: sustainability as an objective in international agricultural research. *Agricultural Economics* 3(4): 381-398.

Mabuhay, J. A., Nakagoshi, N. and Horikoshi, T. (2003). Microbial biomass and abundance after forest fire in pine forests in Japan. *Ecological Research* 18(4): 431-441.

Madejón, E., Diaz, M. J., Lopez, R. and Cabrera, F. (2001). Co-composting of sugarbeet vinasse: influence of the organic matter nature of the bulking agents used. *Bioresources Technology* 76, 275-278.

Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P. and Niggli, U. (2002). Soil fertility and biodiversity in organic farming. *Science* 296(5573): 16941697.

Mafongoya, P., Barak, P. and Reed, J. (2000). Carbon, nitrogen and phosphorus mineralization of tree leaves and manure. *Biology and Fertility of Soils* 30(4): 298-305.

Maková, J., Javorekova, S., Medo, J. and Majerčíková, K. (2012). Characteristics of microbial biomass carbon and respiration activities in arable soil and pasture grassland soil. *Journal of Central European Agriculture* 12(4): 745758.

Malik, M. A., Khan, K. S., Marschner, P. and Ali, S. (2013). Organic amendments differ in their effect on microbial biomass and activity and on P pools in alkaline soils. *Biology and Fertility of Soils* 49(4): 415-425.

Maman, N. and Mason, S. (2013). Poultry manure and inorganic fertilizer to improve pearl millet yield in Niger. *African Journal of Plant Science* 7(5): 162-169.

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

Manu, A., Thurow, T., Juo, A., Zanguina, I., Gandah, M. and Mahamane, I. (1994). Sustainable land management in the Sahel: A case study of an agricultural watershed at Hamdallaye, Niger. TropSoils Program, Soils and Crop Sciences Department, Texas A&M University.

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

Marschner, H. (2011). Marschner's mineral nutrition of higher plants. Academic Press. Second edition. London, UK.

Marshall, A. W. (1954). The use of multistage sampling schemes in Monte Carlo computations. pp. 123-140. In H. A. Meyer (eds.). *Symposium on Monte Carlo Methods*. Wiley, New York.

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

Mason, S. C., Maman, N. and Palé, S. (2015). Pearl millet production pratices in semi-arid West Africa: A review. *Experimental Agriculture*: 1-21.

Mazzarino, M., Oliva, L., Abril, A. and Acosta, M. (1991). Factors affecting nitrogen dynamics in a semiarid woodland (Dry Chaco, Argentina). *Plant and Soil* 138(1): 85-98.

McConnell, D. B., Shiralipour, A. and Smith, W. H. (1993). Compost application improves soil properties. *BioCycle* 3:61–63.

McIntire, J., Bourzat, D. and Pingali, P. (1992). Crop-Livestock Interaction in Sub-Saharan Africa. The World Bank, Washington, DC. 246 pp.

McLean, E. O. (1982). Soil pH and lime requirement. pp.199 – 223. In: A.L. Page, R.H. Miller and D.R. Keeney (eds.). *Methods of soil analysis. Part 2. Chemical and microbiological properties. Second edition.* American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA.

Mekonnen, K., Buresh, R. J. and Jama, B. (1997). Root and inorganic nitrogen distributions in *sesbania* fallow, natural fallow and maize fields. *Plant and Soil* 188(2): 319-327.

Melillo, J. M., Aber, J. D. and Muratore, J. F. (1982). Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology* 63(3): 621-626.

Merwad, A.-R. M. and Abdel-Fattah, M. K. (2015). Effect of Some Soil Amendments and Foliar Spray of Salicylic and Ascorbic Acids on Sorghum Under Saline Calcareous Soil Conditions. *International Journal of Soil Science* 10(1): 28.

Meyer, K., Joergensen, R. G. and Meyer, B. (1997). The effects of reduced tillage on microbial biomass C and P in sandy loess soils. *Applied Soil Ecology* 5(1): 71-79.

Misra, R., Roy, R. and Hiraoka, H. (2003). On-farm composting methods. Food and Agriculture Organization of the United Nations. Rome, Italy.

Mohamed, A. R. (2015). Nitrogen mineralization from various manures in saline and non-saline soils. MSc. Thesis, Faculty of Natural Resources and Environmental Studies. University of Kordofan.

Mohammadi, K., Heidari, G., Khalesro, S. and Sohrabi, Y. (2012). Soil management, microorganisms and organic matter interactions: A review. *African Journal of Biotechnology* 10(86): 19840-19849.

Mokolobate, M. and Haynes, R. (2002). Comparative liming effect of four organic residues applied to an acid soil. *Biology and Fertility of Soils* 35(2): 79-85.

Mokwunye, A. U., de Jager, A. and Smaling, E. (1996). Restoring and Maintaining the Productivity of West African Soils: Key to Sustainable Development. Miscellaneous Fertilizer Studies No. 14. IFDC-Africa. Lome, Togo.

Moore, J., Klose, S. and Tabatabai, M. (2000). Soil microbial biomass carbon and nitrogen as affected by cropping systems. *Biology and Fertility of Soils* 31(34): 200-210.

Morel, C., Tiessen, H. and Stewart, J. (1996). Correction for P-sorption in the measurement of soil microbial biomass P by CHCl< sub> 3</sub> fumigation. *Soil Biology and Biochemistry* 28(12): 1699-1706.

Motsara, M. and Roy, R. N. (2008). Guide to Laboratory establishment for plant nutrient analysis. FAO Fertilizer and Plant Nutrition Bulletin. Food and Agriculture Organization, Rome.

Motte, J.-C., Escudié, R., Beaufils, N., Steyer, J.-P., Bernet, N., Delgenès, J.-P. and Dumas, C. (2014). Morphological structures of wheat straw strongly impacts its anaerobic digestion. *Industrial Crops and Products* 52: 695-701.

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

Mucheru, M., Mugendi, D., Micheni, A., Mugwe, J., Kung'u, J., Otor, S. and Gitari, J. (2004). Improved food production by use of soil fertility amendment strategies in the central highlands of Kenya. pp. 583-592. In A. Bationo and M. J. Swift (Eds.). *Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa*. Nairobi, Kenya.

Muehlig-Versen, B., Buerkert, A., Bationo, A. and Roemheld, V. (2003). Phosphorus placement on acid arenosols of the West African Sahel. *Experimental Agriculture* 39(03): 307-325.

Murwira, H. K. (2003). Managing Africa's soils: Approaches and Challenges. pp. 306. In: M.P. Gichuru, A. Bationo, M.A. Bekunda, H.C. Goma, P.L. Mafangoya, D.N. Mugendi, H.M. Murwira, S.M. Nandwa, P. Nyathi, and M. Swift (eds.). *Soil fertility management in Africa: A regional perspective.* Academy Science, Nairobi, Kenya.

Mutuo, P., Mukalama, J. and Agunda, J. (2000). On-farm testing of organic and inorganic phosphorous source on maize in Western Kenya. The biology and fertility of tropical soils: Tropical Soil Biology and Fertility (TSBF), report: 22.

Muza, L. and Mapfumo, P. (1999). Constraints and opportunities for legumes in the fertility enhancement of sandy soils in Zimbabwe. Maize Production Technology for the Future: Challenges and Opportunities. Proceedings of the

Eastern and Southern Africa Regional Maize Conference, 6; Addis Ababa, Ethiopia; 21-25 September.

Muzira, R. N., Amoding, A. and Bekunda, M. A. (2003). Preparing compost and silage from water hyacinth. pp. 75-79. In C.E.N. Savala, M.A. Omare and P.L. Woomer (eds.). *Organic Resource Management in Kenya: Perspectives and Guidelines.* Nairobi, Kenya.

Myers, R., Palm, C. A., Cuevas, E., Gunatilleke, I. and Brossard, M. (1994). The synchronisation of nutrient mineralisation and plant nutrient demand. pp. 81116. In P. L. Woomer and M. J. Swift (eds.). *The biological management of tropical fertility*. Chichester. Londres, UK.

Nhamo, N. (2001). An Evaluation of the Efficacy of Organic and Inorganic Fertilizer Combinations in Supplying Nitrogen to Crops, MSc. Thesis. Harare, Zimbabwe: University of Zimbabwe.

Nhamo, N., Martius, C., Wall, P. C. and Thierfelder, C. (2007). The fate of surface residue mulch during the dry winter and spring seasons in Zimbabwe. Conference on International Agricultural Research for Development. University of Kassel-Witzenhausen and University of Göttingen, 9-11th October.

Nolan, T., Troy, S. M., Healy, M. G., Kwapinski, W., Leahy, J. J. and Lawlor, P. G. (2011). Characterization of compost produced from separated pig manure and a variety of bulking agents at low initial C/N ratios. *Bioresource Technology* 102(14): 7131-7138.

Nolte, C., Zo'o, B. O. and Dondjang, J. P. (2007). Farmer‟s perception of planted calliandra tree fallows for shortening fallow cycles in southern Cameroon. pp 921-932. In A. Batiano, B. Waswa, J. Kihira and J. Kimetu (eds.). *Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities*. Springer, Netherlands.

Norris, G., Qureshi, F., Howitt, D. and Cramer, D. (2014). Introduction to statistics with Statistical Package for Social Sciences (SPSS). Routledge. New York, USA. 454 pp.

Novoa, R. and Loomis, R. (1981). Nitrogen and plant production. *Plant and Soil* 58(1-3): 177-204.

Nziguheba, G. (2007). Overcoming phosphorus deficiency in soils of Eastern Africa: recent advances and challenges. pp. 149-160. In A. Batiano, B. Waswa, J. Kihira and J. Kimetu (eds.). *Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities*. Springer, Netherlands.

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

Oad, F., Buriro, U. and Agha, S. (2004). Effect of organic and inorganic fertilizer application on maize fodder production. *Asian Journal of Plant Sciences* 3(3): 375-377.

Oberson, A., Friesen, D., Morel, C. and Tiessen, H. (1997). Determination of phosphorus released by chloroform fumigation from microbial biomass in high P sorbing tropical soils. *Soil Biology and Biochemistry* 29(9): 15791583.

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

Omae, H., Saidou, A. and Tobita, S. (2014). On-farm Evaluation of Effect of Organic and Mineral Fertilizer on Biomass and Yield of Millet/Cowpea Intercrop in the Sahel, West Africa. *Journal of Life Sciences* 8(7): 582-592.

Omare, M. N. and Woomer, P. L. (2002). Innovations in organic resource management: experiences from Kenya's Forum for Organic Resource Management and Agricultural Technologies. *Outlook on Agriculture* 31(4): 235-242.

Oo, A., Iwai, C. and Saenjan, P. (2015). Soil Properties and Maize Growth in Saline and Non-saline Soils using Cassava ‐ Industrial Waste Compost and Vermicompost with or Without Earthworms. *Land Degradation and Development* 26(3): 300-310.

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

Ouédraogo, E., Mando, A. and Zombré, N. (2001). Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. *Agriculture, Ecosystems and Environment* 84(3): 259-266.

Ouédraogo, E., Stroosnijder, L., Mando, A., Brussaard, L. and Zougmoré, R. (2007). Agroecological analysis and economic benefit of organic resources and fertiliser in till and no-till sorghum production after a 6-year fallow in semi-arid West Africa. *Nutrient Cycling in Agroecosystems* 77(3): 245-256.

Ouendeba, B., Siaka, S. B. and Kumar, K. A. (2002). Stratégies de sélection du mil pour les populations galopantes du Sahel. Présentation à la réunion du CFC « Utilization of Regional Germplasm in the Improvement of Sorghum and Pearl Millet and Improved Post-Harvest Technologies » tenue du 23 au 26 Avril 2002. ICRISAT-Niger.

Oyedeji, S., Animasaun, D. A., Bello, A. A. and Agboola, O. O. (2014). Effect of NPK and Poultry Manure on Growth, Yield, and Proximate Composition of Three Amaranths. *Journal of Botany* 2014, 1-6.

Page, A., Miller, R. and Keeney, D. (1982). Total carbon, organic carbon, and organic matter. Methods of soil analysis. *Part* 2: 539-579.

Page, A. L. (1982). Methods of soil analysis. Part 2. Chemical and microbiological properties. CAB International. 1159 pp.

Palm, C. A, Myers, R. J. and Nandwa, S. M. (1997a). Organic-inorganic nutrient interactions in soil fertility replenishment. pp 193–218. In: R.J. Buresh, P.A. Sanchez and F. Calhoun (eds.). *Replenishing Soil Fertility in Africa.* Soil Science Society of America Special Publication, Soil Science Society of America. Madison, WI. USA.

Palm, C. A., Myers, R. J. and Nandwa, S. M. (1997b). Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. pp. 193-217. In R. J. Buresh, P. A. Sanchez, and F. Calhoun (eds.). *Replenishing Soil in Africa.* SSSA Special Publication. Madison, WI. USA.

Palm, C. and Sanchez, P. (1990). Decomposition and nutrient release patterns of the leaves of three tropical legumes. *Biotropica*: 330-338.

Palm, C. and Sanchez, P. (1991). Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biology and Biochemistry* 23(1): 83-88.

Palm, C. A. (1995). Contribution of agroforestry trees to nutrient requirements of intercropped plants. pp. 105-124. In F. L. Sinclair (eds.). *Agroforestry: Science, Policy and Practice*. Springer, Netherlands.

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G. and Giller, K. E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture, Ecosystems and Environment* 83(1): 27-42.

Palm, C. A. and Sanchez, P. A. (2000). Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biology Biochemistry*. 23, 83-88.

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

Partey, S. T., Preziosi, R. F. and Robson, G. D. (2013). Maize residue interaction with high quality organic materials: effects on decomposition and nutrient release dynamics. *Agricultural Research* 2(1): 58-67.

Paustian, K., Agren, G. and Bosatta, E. (1997). Modelling litter quality effects on decomposition and soil organic matter dynamics. pp. 313-336. In G.Cadisch and K. E. Giller (eds.). *Driven by Nature: Plant Litter Quality and Decomposition*, CAB International, Wallingford, UK.

Payne, R. and Committee, L. A. T. (2006). GenStat for Windows 9th Edition Introduction. VSN International, UK.

Peacock, A. g., Mullen, M., Ringelberg, D., Tyler, D., Hedrick, D., Gale, P. and White, D. (2001). Soil microbial community responses to dairy manure or ammonium nitrate applications. *Soil Biology and Biochemistry* 33(7): 10111019.

Peigné, J. and Girardin, P. (2004). Environmental impacts of farm-scale composting practices. *Water, Air, and Soil Pollution* 153(1-4): 45-68.

Pérez-Harguindeguy, N., Díaz, S., Garnier, E., Lavorel, S., Poorter, H., Jaureguiberry, P., Bret-Harte, M., Cornwell, W., Craine, J. and Gurvich, D. (2013). New handbook for standardised measurement of plant functional traits worldwide. *Australian Journal of Botany* 61(3): 167-234.

Perucci, P. (1990). Effect of the addition of municipal solid-waste compost on microbial biomass and enzyme activities in soil. *Biology and Fertility of Soils* 10(3): 221-226.

Perucci, P., Dumontet, S., Bufo, S., Mazzatura, A. and Casucci, C. (2000). Effects of organic amendment and herbicide treatment on soil microbial biomass. *Biology and Fertility of Soils* 32(1): 17-23.

Powell, J. and Mohamed-Saleem, M. (1987). Nitrogen and phosphorus transfers in a crop-livestock system in West Africa. *Agricultural Systems* 25(4): 261-277.

Probert, M. E., Delve, R. J., Kimani, S. and Dimes, J. P. (2005). Modelling nitrogen mineralization from manures: Representing quality aspects by varying C: N ratio of sub-pools. *Soil Biology and Biochemistry* 37(2): 279287.

Purnomo, E., Black, A. and Conyers, M. (2000). The distribution of net nitrogen mineralisation within surface soil. 2. Factors influencing the distribution of net N mineralisation. *Soil Research* 38(3): 643-652.

Rahman, M. M., Tsukamoto, J., Rahman, M. M., Yoneyama, A. and Mostafa, K. M. (2013). Lignin and its effects on litter decomposition in forest ecosystems. *Chemistry and Ecology* 29(6): 540-553.

Raich, J. and Schlesinger, W. H. (1992). The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus B* 44(2): 81-99.

Ramdani, N., Lousdad, A. and Hamou, A. (2015). Study of the biodegradation and fertility of the co-composting produced from sewage sludge and green waste and its effects on the speciation of heavy metals. *Journal Materials and Environmental Science* 6 (5) 1310-1320.

Rasul, G. (1999). Sustainability analysis of modern and ecological farming systems in Delduar Thana, Bangladesh. MSc. Thesis. School of Environment, Resources and Development, Asian Institute of Technology, Thailand.

Reddy, K., Khaleel, R. and Overcash, M. (1980). Carbon transformations in the land areas receiving organic wastes in relation to nonpoint source pollution: A conceptual model. *Journal of Environmental Quality* 9(3): 434-442.

Reinertsen, S. A., Elliott, L., Cochran, V. and Campbell, G. (1984). Role of available carbon and nitrogen in determining the rate of wheat straw decomposition. *Soil Biology and Biochemistry* 16(5): 459-464.

Rengel, Z. (2007). The role of crop residues in improving soil fertility. pp. 183-214. In Marschner, Petra, Rengel and Zdenko (eds.). *Nutrient cycling in terrestrial ecosystems*. Springer-Verlag Berlin Heidelberg.

RGAC (Recensement General de l'Agriculture et du Cheptel) (2008). Productivité des exploitations Agricoles. Résultats Définitifs. Volume VI. 25 pages.

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

Rick, T. L., Jones, C. A., Engel, R. E. and Miller, P. R. (2011). Green manure and phosphate rock effects on phosphorus availability in a northern Great Plains dryland organic cropping system. *Organic Agriculture* 1(2): 81-90.

Saidou, A. K., Bassirou, A., Mamadou, A. and Adakal, H. (2014). Effect of compost amended with urea on crops yields in a strip cropping system millet/cowpea on sandy soil poor in P. *Research Journal of Agricultural and Environmental Sciences* 1(2) 23-28.

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

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

Sarwar, G., Hussain, N., Schmeisky, H. and Muhammad, S. (2007). Use of compost an environment friendly technology for enhancing rice-wheat production in Pakistan. *Pakistan Journal of Botany* 39(5): 1553-1558.

Sarwar, G., Schmeisky, H., Hussain, N., Muhammad, S., Ibrahim, M. and Safdar, E. (2008). Improvement of soil physical and chemical properties with compost application in rice-wheat cropping system. *Pakistan Journal of Botany* 40(1): 275-282.

Schlecht, E. and Buerkert, A. (2004). Organic inputs and farmers' management strategies in millet fields of western Niger. *Geoderma* 121(3): 271-289.

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

Schrack, D. (2009). USDA Toughens Oversight of Organic Fertilizer: Organic fertilizer must undergo testing. The Packer. http://www.organicconsumers.org/articles/article_17001. cfm. Retrieved November 19.

Schroth, G. (2003). Decomposition and nutrient supply from biomass. pp. 131–150. In: G. Schrot and F.L. Sinclair (Eds.). *Trees, Crops and Soil Fertility: Concepts and Research Methods.* CABI International, Wallingford, UK,

Scoones, I. and Toulmin, C. (1998). Soil nutrient balances: what use for policy? *Agriculture, Ecosystems and Environment* 71(1): 255-267.

Sedogo, P., Bado, B., Hien, V. and Lompo, F. (1991). Utilisation efficace des engrais azotés pour une augmentation de la production vivrière: L"expérience du Burkina Faso. pp. 115-123. In A. U. Mokwunye (eds.). *Alleviating Soil Fertility Constraints to Increased Crop Production in West Africa*. Springer, Netherlands.

Seneviratne, G. (2000). Litter quality and nitrogen release in tropical agriculture: A synthesis. *Biology and Fertility of Soils* 31(1): 60-64.

Seran, T., Srikrishnah, S. and Ahamed, M. (2010). Effect of different levels of inorganic fertilizer and compost as basal application on the growth and yield of onion (*Allium cepa* L.). *Journal of Agricultural Science* 5: 64-70.

Shah, S. A., Shah, S. M., Mohammad, W., Shafi, M. and Nawaz, H. (2009). N uptake and yield of wheat as influenced by integrated use of organic and mineral nitrogen. *International Journal of Plant Production* 3(3): 45-56.

Sharma, B., Molden, D. and Cook, S. (2015). Water use efficiency in agriculture: Measurement, current situation and trends. pp. 39-64. In P. Drechsel, P. Heffer, H. Magen, R. Mikkelsen and D. Wichelns (Eds.). *Managing Water and Fertilizer for Sustainable Agricultural Intensification*. International Fertilizer Industry Association (IFA), International Water Management Institute (IWMI), International Plant Nutrition Institute (IPNI), and International Potash Institute (IPI). First edition, Paris, France.

Sharpley, A., Rekolainen, S., Tunney, H., Carton, O., Brookes, P. and Johnston, A. (1997). Phosphorus in agriculture and its environmental implications. pp. 1-53. In O. T. Carton, P. C. Brookes and A. E. Johnston (eds.). *Phosphorus loss from soil to water*. CABI International. Wallingford, UK.

Shi, J. (2013). Decomposition and Nutrient Release of Different Cover Crops in Organic Farm Systems. MSc. Thesis, College at the University of Nebraska.

Shibabaw, A. and Melkamu, A. (2015). The Contribution of Some Soil and Crop Management Practice on Soil Organic Carbon Reserves: Review. *Journal of Advances in Agriculture* 3(3):. 227-277.

SIG-Niger (System d'Information Géographique-Niger) (2013). Niger' database terrain.

Singh, R., Das, S., Rao, B. and Reddy, N. (1990). Towards sustainable dryland agricultural practices. Central Research Institute Dryland Agriculture, Hyderabad, India.106.

Singh, S., Ghoshal, N. and Singh, K. (2007). Variations in soil microbial biomass and crop roots due to differing resource quality inputs in a tropical dryland agroecosystem. *Soil Biology and Biochemistry* 39(1): 76-86.

Spaccini, R., Piccolo, A., Mbagwu, J., Zena Teshale, A. and Igwe, C. (2002). Influence of the addition of organic residues on carbohydrate content and structural stability of some highland soils in Ethiopia. *Soil Use and Management* 18(4): 404-411.

Sparling, G. P. (1992). Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. *Soil Research* 30(2): 195-207.

Stanford, G. and Smith, S. (1972). Nitrogen mineralization potentials of soils. *Soil Science Society of America Journal* 36(3): 465-472.

Suge, J., Omunyin, M. and Omami, E. (2011). Effect of organic and inorganic sources of fertilizer on growth, yield and fruit quality of eggplant (*Solanum Melongena* L). *Archives of Applied Science Research* 3(6): 470-479.

Suzuki, K., Matsunaga, R., Hayashi, K., Matsumoto, N., Tabo, R., Tobita, S. and Okada, K. (2014). Effects of traditional soil management practices on the nutrient status in Sahelian sandy soils of Niger, West Africa. *Geoderma* 223: 1-8.

Sweeten, J. M. and Auvermann, B. W. (2008). Composting manure and sludge. *Agrilife Extension* E-479, 06-08. Texas A&M System.

Sydorovych, O. and Wossink, A. (2008). The meaning of agricultural sustainability: evidence from a conjoint choice survey. *Agricultural Systems* 98(1): 10-20.

Szanto, G., Hamelers, H., Rulkens, W. and Veeken, A. (2007). NH_3, N_2O and CH_4 emissions during passively aerated composting of straw-rich pig manure. *Bioresource Technology* 98(14): 2659-2670.

Tabo, R., Bationo, A., Gerard, B., Ndjeunga, J., Marchal, D., Amadou, B., Annou, M. G., Sogodogo, D., Taonda, J.-B. S. and Hassane, O. (2007). Improving cereal productivity and farmers" income using a strategic application of fertilizer in West Africa. pp. 201-208. In A. Batiano, B. Waswa, J. Kihira and J. Kimetu (eds.). *Advances in integrated soil fertility management in sub-Saharan Africa: Challenges and opportunities*. Springer, Netherlands.

Tarfo, B. D., Chude, V. O., Iwuafor, E. N. O. and Yaro, D. T. (2001). Effects of the combined application of millet thresh waste, cow dung and fertilizer on maize nutrient concentrations and uptake. *Chemclass Journal.* 32 (2): 144151.

Teklay, T., Nordgren, A., Nyberg, G. and Malmer, A. (2007). Carbon mineralization of leaves from four Ethiopian agroforestry species under laboratory and field conditions. *Applied Soil Ecology* 35(1): 193-202.

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

Theng, B., Tate, K., Sollins, P. and Moris, N. (1989). Constituents of organic matter in temperate and tropical soils. pp. 5.31. In D. C. Coleman, J. M. Oades and G. Uehara (eds.). *Dynamics of soil organic matter in tropical ecosystems*. University of Hawaii. Press, Honolulu.

Thuita, M. (2007). A comparison between the "MBILI" and conventional intercropping systems on root distribution, uptake of N and P yields of intercrops in western Kenya. M. Phil Thesis, Moi University, Eldoret, Kenya.

Tian, G., Kang, B. and Brussaard, L. (1992). Effects of chemical composition on N, Ca, and Mg release during incubation of leaves from selected agroforestry and fallow plant species. *Biogeochemistry* 16(2): 103-119.

Tilahun-Tadesse, F., Nigussie-Dechassa, R., Wondimu, B. and Setegn, G. (2013). Effect of farmyard manure and inorganic fertilizer on the growth, yield and moisture stress tolerance of rain-fed lowland rice *American Journal of Research Communication* 1: 275–301

Tiquia, S. (2005). Microbiological parameters as indicators of compost maturity. *Journal of Applied Microbiology* 99(4): 816-828.

Tisdale, S. L., Nelson, W. L. and Beaton, J. D. (1985). Soil fertility and fertilizer. 4th edition Macmillan Publisher. Co., New York.

Tisdell, C. (1996). Economic indicators to assess the sustainability of conservation farming projects: an evaluation. *Agriculture, Ecosystems and Environment* 57(2): 117-131.

Tomati, U., Madejon, E. and Galli, E. (2000). Evolution of humic acid molecular weight as an index of compost stability. *Compost Science and Utilization* 8(2): 108-115.

Traore, S. and Harris, P. J. (1995). Long-Term Fertilizer and Crop Residue Effects on Soil and Crop Yields in the Savanna Region of Côte d'Ivoire'. pp. 141– 180. In R. Lal and B. A. Stewart (eds.). *Soil Management: Experimental Basis for Sustainability and Environmental Quality*. CRC/Lewis Publishers, Boca Raton, New York.

Troeh, F. R. and Thompson, L. M. (2005). Soils and soil fertility. Oxford University Press, 5th edition. New York.

Tuomela, M., Vikman, M., Hatakka, A. and Itävaara, M. (2000). Biodegradation of lignin in a compost environment: A review. *Bioresource Technology* 72(2): 169-183.

Vance, E., Brookes, P. and Jenkinson, D. (1987). An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry* 19(6): 703-707.

Vanlauwe, B., Diels, J., Aihou, K., Iwuafor, E., Lyasse, O., Sanginga, N. and Merckx, R. (2001a). Direct interactions between N fertilizer and organic matter: evidence from trials with 15N-labelled fertilizer. pp. 173-184. In B. Vanlauwe, J. Diels, N. Sanginga and R. Merckx (eds.). *Integrated Plant Nutrient Management in Sub-Saharan Africa.* From Concept to Practice. CAB International, New York, USA.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R. and Six, J. (2011). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant and Soil* 339(1-2): 35-50.

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

Vanlauwe, B., Sanginga, N. and Merckx, R. (1997). Decomposition of four< i> *Leucaena*</i> and< i> Senna</i> prunings in alley cropping systems under sub-humid tropical conditions: The process and its modifiers. *Soil Biology and Biochemistry* 29(2): 131-137.

Vanlauwe, B., Wendt, J. and Diels, J. (2001b). Combined application of organic matter and fertilizer. pp. 247–279. In G. Tian, F. Ishida and J.D.H. Keatinge (eds.). *Sustaining Soil Fertility in West Africa.* SSSA Special Publication, Madison, WI, USA.

Verkaik, E., Jongkind, A. G. and Berendse, F. (2006). Short-term and long-term effects of tannins on nitrogen mineralisation and litter decomposition in kauri (*Agathis australis* (D. Don) Lindl.) forests. *Plant and Soil* 287(1-2): 337-345.

Vittal, K., Sankar, G. M., Singh, H. and Samra, J. (2002). Sustainability of Practices of Dryland Agriculture - Methodology and Assessment. Research Bulletin of AICRP for Dryland Agriculture, CRIDA, Hyderabad, 100 pages.

Vogel, H., Nyagumboz, I. and Olsen, K. (1994). Effect of tied riding and mulch ripping on water conservation in Maize production on sandveld soils. *Der Tropenlandwirt-Journal of Agriculture in the Tropics and Subtropics* 95(1): 33-44.

Vogt, K. A., Grier, C. C. and Vogt, D. (1986). Production, turnover, and nutrient dynamics of above-and belowground detritus of world forests. *Advances in Ecological Research* 15: 303-377.

Volk, V. and Ullery, C. (1993). Department of Soil Science. Oregon state University, Coruallis, 50 p.

Wang, Q., Li, Y. and Klassen, W. (2007). Changes of soil microbial biomass carbon and nitrogen with cover crops and irrigation in a tomato field. *Journal of Plant Nutrition* 30(4): 623-639.

Wang, W., Baldock, J. A., Dalal, R. and Moody, P. (2004). Decomposition dynamics of plant materials in relation to nitrogen availability and biochemistry determined by NMR and wet-chemical analysis. *Soil Biology and Biochemistry* 36(12): 2045-2058.

Warman, P. and Cooper, J. (2000). Fertilization of a mixed forage crop with fresh and composted chicken manure and NPK fertilizer: Effects on soil and tissue Ca, Mg, S, B, Cu, Fe, Mn and Zn. *Canadian Journal of Soil Science* 80(2): 345-352.

Weil, R. and Kroontje, W. (1979). Physical condition of a Davidson clay loam after five years of heavy poultry manure applications. *Journal of Environmental Quality* 8(3): 387-392.

Wezel, A. and Haigis, J. (2002). Fallow cultivation system and farmers' resource management in Niger, West Africa. *Land Degradation and Development* 13(3): 221-231.

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

Whitbread, A., Jiri, O., Maasdorp, B. and Pengelly, B. (2004). The movement and loss of soil nitrate and labile C in a tropical forage legume/maize rotation in Zimbabwe. http://www.sfst.org/proceedings/17WCS-CD/Abstracts/0719.pdf. Accessed Jan. 2014

Wiart, J. (2000). Compost: Situation, present management and perspectives. *Techniques Sciences Méthodes* 10: 20-27.

Xu, X., Zhang, T. and Liu, Z. (2008). Calibration model of microbial biomass carbon and nitrogen concentrations in soils using ultraviolet absorbance and soil organic matter. *European Journal of Soil Science* 59(4): 630-639.

Yaduvanshi, N. (2003). Substitution of inorganic fertilizer by organic manures and the effect on soil fertility in a rice–wheat rotation on reclaimed sodic soil in India. *The Journal of Agricultural Science* 140(02): 161-168.

Yassen, A., Khaled, S. and Sahar, M. Z. (2010). Response of wheat to different rates and ratios of organic residues on yield and chemical composition under two types of soil. *Journal of American Science* 6(12): 858-864.

Yinbo, G., Peoples, M. B. and Rerkasem, B. (1997). The effect of N fertilizer strategy on N 2 fixation, growth and yield of vegetable soybean. *Field Crops Research* 51(3): 221-229.

Zebarth, B., Neilsen, G., Hogue, E. and Neilsen, D. (1999). Influence of organic waste amendments on selected soil physical and chemical properties. *Canadian Journal of Soil Science* 79(3): 501-504.

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

Zheng, S. J. (2010). Crop production on acidic soils: overcoming aluminium toxicity and phosphorus deficiency. *Annals of botany* 106(1): 183-184.

Zhu, N. (2007). Effect of low initial C/N ratio on aerobic composting of swine manure with rice straw. *Bioresource Technology* 98: 9-13.

Zougmoré, R., Mando, A., Stroosnijder, L. and Ouédraogo, E. (2005). Economic benefits of combining soil and water conservation measures with nutrient management in semiarid Burkina Faso. *Nutrient Cycling in Agroecosystems* 70(3): 261-269.

APPENDICES

Appendix 1: Questionnaire used during the survey in the Dan Saga – Niger

Name of interviewer: Date:

Location: Signature:

Region: Department:

Communal: Village:

A. **Personnel information**

1. Name:
2. Gender: 1. Male [ ] 2. Female [ ]
3. Age

i. 18-24 [ ] iv. 45-54 [ ]

ii. 25-34 [ ] v. 55-64 [ ]

iii. 35-44 [ ] vi. Over 65 [ ]

4. Ethnicity

i. Haoussa [ ] ii. Peulh [ ]

iii. Other: …………………………..

5. Marital status:

i. Single [ ] iv. Widow/er [ ]

ii. Married [ ] v. Others…………………… iii. Divorced [ ]

6. Level of education:

i. Illiterate [ ] iii. Secondary [ ]

ii. Primary [ ] iv. Quranic [ ]

7. Occupation

i. Main occupation/income……………………………….

ii. Other (s) specify……………………….……………………

B. Information on crops residues management

8. How many fields do you have?

Field	Size
1	
2	
3	
4	
5	
Total area	

9. Which of the following crops do you cultivate?

i. Millet [ ]

ii. Cowpea [ ]

iii. Sorghum [ ] iv.

Groundnut [ ]

v. Other(s), specify……………………………………………………………

10. Do you leave crop residue in your field after harvest? Yes [ ] No [ ] If yes;

11. Which of these crop residues do you leave in your fields after harvest?

i. Millet [ ]

ii. Cowpea [ ]

iii. Sorghum [ ] iv.

Groundnut [ ]

v. Other(s), specify…………………………………………………………………

12. If yes to millet,

a. Can you estimate the quantity that you get after harvest?

Residues	Quantity
Millet straw	
Millet glume	

b. Do you pay for millet residues?

Yes [ ] No [ ]

If yes, how much do you pay per bag/ (local measure)? .... c. Do you always get the quantity needed?

Yes [ ] No [ ]

13. If no, why?

	Millet straw	Millet glume
i. Unavailability	[ ]	[ ]
ii. Inaccessibility	[ ]	[ ]
iv. Insufficient	[ ]	[ ]

viii. Other(s), specify…………………………………………….

C. Information on manure and mineral fertilizer management

14. Do you apply any mineral fertilizer?

15. If yes,

a. What type (s) and quantity?

Mineral fertilizer	Quantity	Prize
NPK		
DAP		
TSP		
SSP		
Urea		
Other (s) specify		

b. Do you apply the recommended rate of mineral fertilizer?

Yes [ ] No [ ]

16. If no, why?

i. High fertilizer cost [ ]

ii. Unavailability of fertilizer to purchase [ ]

iii. No knowledge about fertilizer use [ ]

vi. Other(s), specify…………………………………………………

17. Do you apply organic fertilizer (manure and others)?

Yes [ ] No [ ]

a. If yes, what type (s) of manure do you apply?

i. Cow dung [ ]

ii. Sheep/goat manure [ ]

iii. Household waste [ ]

iv. Others (s), specify…………………………………………………

b. Do you pay for it?

Yes [ ] No [ ]

c. Do you always get the quantity needed?

Yes [ ] No [ ]

d. How much do you pay per bag or local measure?

i. Cow dung…………………………………………………………..

ii. Sheep/goat manure…………………………………………………

iii. Household waste………………………………………………….

iv. Others (s), specify………………………………………………

18. If no, why?

i. No animals [ ]

ii. Laborious to collect [ ] iii.

Inaccessibility [ ]

v. Other(s) specify……………………………………………………

D. Information on composting from crop residues and manure

19. Do you apply the combination of organic and inorganic fertilizer in your field?

Yes [ ] No [ ]

20. If yes, what method of combination do you use?

i. Composting [ ]

ii. Timing application [ ]

iii. Other (s) specify………………………………………………

21. Do you have an experience about millet straw-based compost?

Yes [ ] No [ ]

22. If yes, which of the following materials do you use to prepare compost?

i. Millet rachis Yes [ ] No [ ]

ii. Millet glume Yes [ ] No [ ]

iii. Cow dung Yes [ ] No [ ]

iv. Sheep/goat manure Yes [ ] No [ ]

v. Ash Yes [ ] No [ ]

viii. Other(s) specify…………………………………………………..

23. How do you prepare the compost?

…………………………………………………………………………………

24. How long does the preparation take before maturity of the compost?

i. Three months Yes [ ]

ii. Six months Yes [ ]

iii. Other(s), specify ………………………………………

25. If no, why you can‟t prepare compost of millet straw?

……………………………………………………………………………………

26. Do you pay for compost?

Yes [ ] No [ ]

a. If yes, how much do you pay a bag or local measure? ....

27. Do you have experience about millet glume-based compost?

Yes [ ] No [ ]

28. If yes, how do you prepare it?

………………………………………………………………………………………………

29. How long does the preparation take before maturity of the compost?

i. Three months Yes [ ]

ii. Six months Yes [ ]

iii. Other(s), specify …………………………………………………..

30. Do you pay for millet glume-based compost?

Yes [ ] No [ ]

a. If yes, how much do you pay a bag or local measure of millet glume-based compost?

………………………………………………………………………………………………

b. If no, why you can"t you prepare millet glume-based compost?

………………………………………………………………………………………………

31. Can you estimate how much compost you apply in your field?

Yes [ ] No [ ] If yes, estimate the quantity?

Fertilizer	Quantity
Millet straw-based compost	
Millet glume-based compost	
Other(s)	

32. Do you get always the quantity needed?

Yes [ ] No [ ]

a. Millet straw-based compost [ ] [ ]
b. Millet glume-based compost [ ] [ ]
c. Other(s) specifiy……………………………………………………

33. If no, would you be willing to buy such a product?

Yes [ ] No [ ]

If yes, which one of the below?

a. Millet straw-based compost [ ] [ ]
b. Millet glume -based compost [ ] [ ]
c. Other(s) specifiy……………………………………….……………………

34. Since when have you been using compost? ....

35. How much did you pay for your fertilizer application (per bag or local measure)?

i. Millet glume………………………… ……………..……………………

ii. Manure………………………………………………………………………

iii. Compost……………………………………..………………………………

iv. Inorganic fertilizer………………………..………………………………

v. Other (s): Incorporation by personnel labour Yes [ ] No [ ]

36. What are the effects of compost on soil and crop production?

i. Soil fertility restoration Yes [ ] No [ ]

ii. Maintain soil fertility Yes [ ] No [ ] iii.

High crops yields Yes [ ] No [ ]

iv. Other(s) specify………………………………………………………………

37. Any other comments? ....

Appendix 2: Demographic features of respondents

Respondents (n=100)	Millet glume compost (n=32)		Millet straw compost (n=68)		Pooled (n=100)	
	Freq.	%	Freq.	%	Freq.	%
Gender						
Male	28	87.5	57	83.8	85	85
Female	4	12.5	11	16.2	15	15
Age (years)						
<30	11	34.4	17	25	28	28
31-60	21	65.6	45	66.2	66	66
>61	0	0	6	8.8	6	6
Level of education						
Illiterates	14	43.8	25	36.8	39	39
Primary	13	40.6	20	29.4	33	33
Secondary	2	6.3	3	4.4	5	5
Quranic	3	9.4	20	29.4	23	23
Ethnicity						
Haoussa	24	75	59	86.8	83	83
Peulh	8	25	9	13.2	17	17
Matrimonial status						
Single	2	6.3	1	1.5	3	3
Married	25	78.1	59	86.8	84	84
Divorced	4	12.5	5	7.3	9	9
Widow/er	1	3.1	3	4.4	4	4
Main occupation						
Agriculture	15	46.9	38	55.9	53	53
livestock	10	31.3	22	32.3	32	32
trader	4	12.5	4	5.9	8	8
lecturer	1	3.1	1	1.5	2	2
household	1	3.1	2	2.9	3	3
barber	1	3.1	1	1.5	2	2
Years of using compost 1 to 10	25	78.1	40	58.8	47	47
11 to 20	3	9.4	9	13.3	9	9
21 to 30	0	0	2	2.9	2	2
Don't know	4	12.5	17	25	42	42
					Mean	Std. dev.
Age (years)					39.69	13.59
Field size (ha)					2.53	0.15

Source: Field survey, 2013; Freq., frequency **Appendix 3**: Respondents" assessment on practices for soil fertility management

Respondents (n=100)	Millet glume compost (n=32)		Millet straw compost (n=68)		Pooled (n=100)	
	Freq.	%	Freq.	%	Freq.	%
Inorganic fertilizer used						
Yes	29	90.6	56	82.4	85	85
No	3	9.4	12	17.6	15	15
NPK used						
Yes	11	34.4	18	26.5	29	29
No	21	65.6	50	73.5	71	71
DAP used						
Yes	12	37.5	26	38.2	38	38
No	20	62.5	42	61.8	62	62
SSP used						
Yes	5	15.6	12	17.6	17	17
No	27	84.4	56	82.4	83	83
Urea used						
Yes	22	68.8	37	54.4	59	59
No	10	31.2	31	45.6	41	41
Millet straw used						
Yes	18	56	22	32	40	40
No	14	44	46	68	60	60
Millet glume used Yes						
	24	75	48	71	72	72
No	8	25	20	29	28	28
Manure used						
Yes	16	50	32	47	48	48
No	16	50	36	53	52	52
Ash used						
Yes	32	100	60	88	92	92
No	0	0	8	12	8	8
Combined used of organic and inorganic fertilizers						
Yes	27	84	54	79	81	81
No	5	16	14	21	19	19

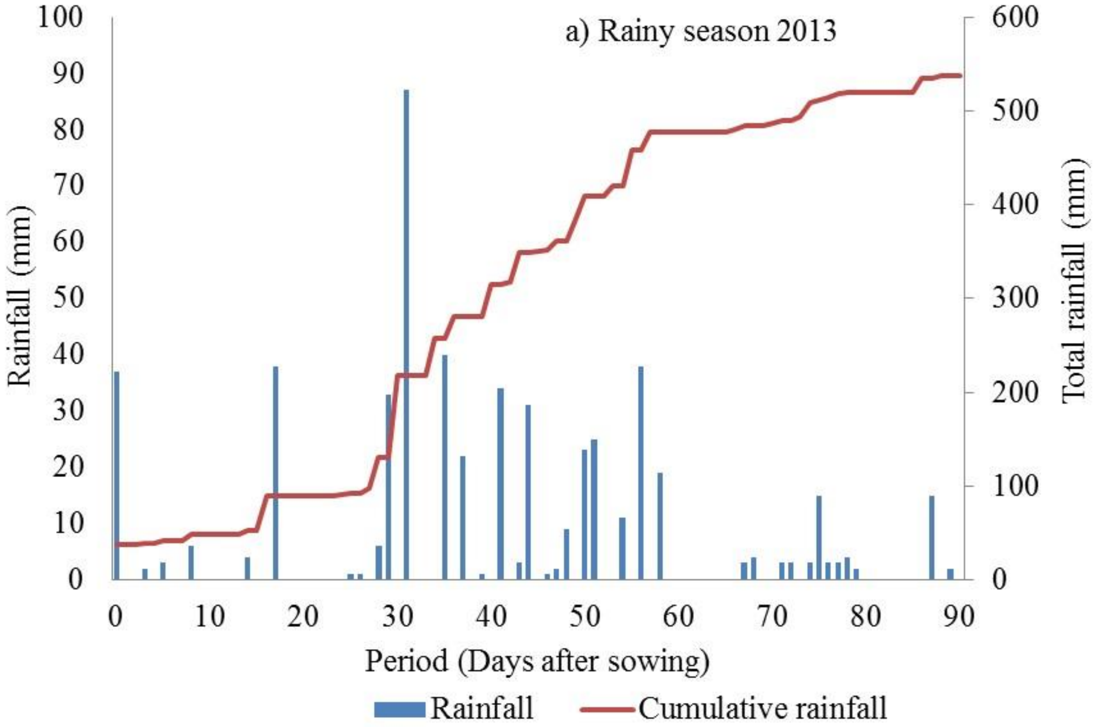
Source: Field survey, 2013; Freq., frequency

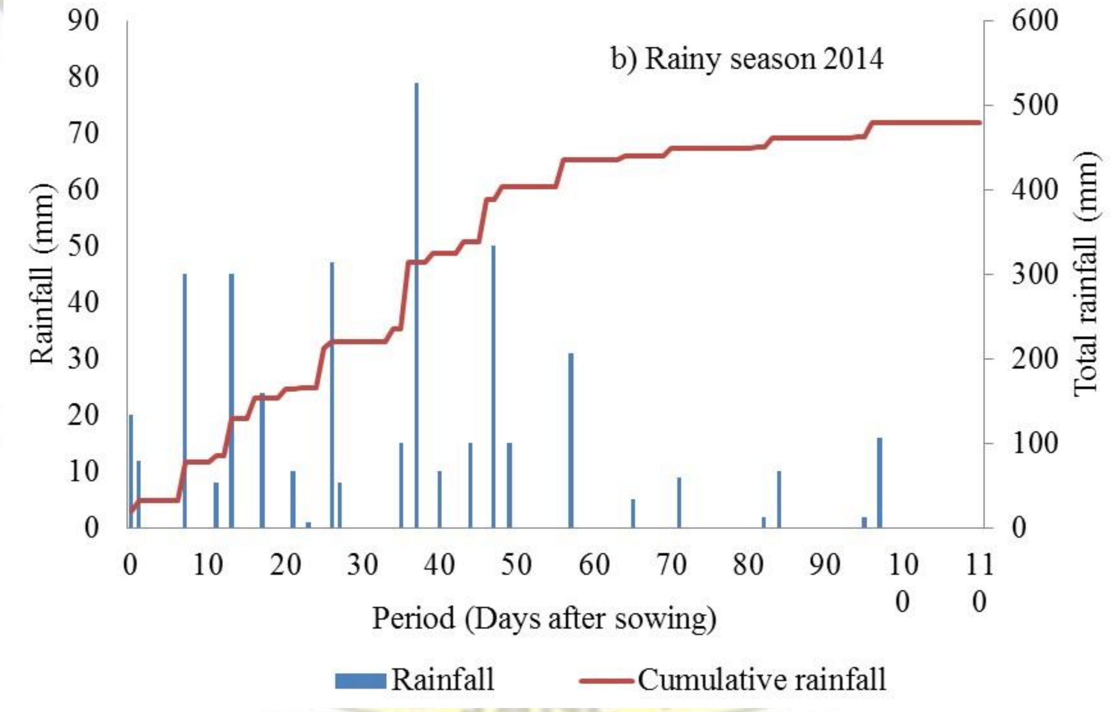
Appendix 4: Respondents willingness to buy compost

Respondents	Millet glume compost (n=32)		Millet straw compost (n=68)		Pooled (n=100)	
	Freq.	%	Freq.	%	Freq.	%
Willing to buy compost						
Yes	25	78	55	81	80	80
No	7	22	13	19	20	20
Effect of compost on soil fertility and crop yield improvement						
Yes	31	97	63	93	94	94
No	1	3	5	7	6	6

	Mean applied (kg ha^{-1})	Std. dev.
Millet glume compost	697	561
Millet straw compost	620	276

Source: Field survey, 2013; Freq., frequency





Appendix 5: Cumulative rainfall (Dry spells are visible as horizontal lines)

Appendix 6: Probability values of interacting effect of year and treatments on soil nutrients and microbial biomass

	Probability												
	pH	OC	Total N	Avail. P	Ca	Mg	K	Na	Exch. acidity (Al + H)	ECEC	MBC	MBN	MBP
Year	0.364	0.048	0.027	< 0.001	0.141	< 0.001	0.192	0.003	0.123	< 0.001	0.045	< 0.001	< 0.001
Treatment	< 0.001	< 0.001	0.146	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Year *x* Treatment	< 0.001	0.177	0.344	< 0.001	0.140	< 0.001	< 0.001	< 0.001	0.010	< 0.001	< 0.001	< 0.001	< 0.001
CV (%)	6.5	28.6	37.2	10.9	12.5	6.4	15.4	18.6	20.0	6.0	17.4	14.1	8.1

Appendix 7: Probability values of interacting effect of year and treatments on millet and cowpea yields

	Probability			
	Millet yield		Cowpea yield	
	Grain	Biomass	Grain	Haulm
Year	0.481	0.030	0.690	0.111
Treatment	< 0.001	< 0.001	< 0.001	< 0.001
Year *x* Treatment	0.133	0.022	0.009	0.002
CV (%)	35.10	26.40	27.10	30.30

Appendix 8: Effect of treatments on soil moisture parameters

Treatments	Moisture content (%)	Bulk density (g/cm3)	Volumetric moisture content (%)	Porosity (%)
$C_0 + N_0 P_{0RR}$	7.53	1.61	12.12	39.20
C_0 + 50% N P_{RR}	9.46	1.59	15.01	40.11
C_0 + 100% N P_{RR}	9.89	1.62	15.97	39.14
$C_{150} + N_0 P_{0RR}$	12.92	1.57	20.17	40.94
C_{150} + 50% N P_{RR}	11.71	1.56	18.22	41.10
C_{150} + 100% N P_{RR}	14.29	1.59	22.61	40.14
$C_{300} + N_0 P_{0RR}$	16.94	1.46	24.49	45.13
C_{300} + 50% N P_{RR}	19.26	1.48	28.41	44.28
C_{300} + 100% N P_{RR}	14.08	1.52	21.37	42.50
L.s.d (5%)	3.38	0.06	4.65	2.32
CV (%)	16.30	2.70	16.10	3.80