EFFECTS OF DIFFERENT ORGANIC RESIDUES ON CARBON SEQUESTRATION, NUTRIENT AVAILABILITY IN SOIL AND MAIZE YIELDS AT KATUMANI, MACHAKOS COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award.

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DECLARATION BY THE SUPERVISORS

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors.

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DEDICATION

This work is dedicated to my beloved family with a special mention to my father Francis Mbaluka and my late mum TeresiaMbaluka for their commitment and sacrifice towards my education.

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ABSTRACT

Reduced farm productivity in smallholder farms is the principal cause of food insecurity in semi- arid parts of Kenya. This is mainly attributed to soil fertility depletion, land degradation, low soil moisture and climate change. Climate change due to increased carbon dioxideemission into the atmosphere has impacted negatively on the food productivity in Africa. The objectives of this study were: 1) to determine the effect of different organic residues on soil carbon accumulation in soil. 2) to determine the effect of organic residues on the availability of nutrients into the soil, and 3) to determine the effect of different organic residues on maize growth and yields. Field studies were carried out in two seasons (2011/2012 short rains and 2012 long rains) at Kenya Agricultural Research Institute (KARI) – Katumani Dry land Research Centre in Machakos County. Maize residues and compost manure were used, under different application methods and a control where no organic residue was applied. This constituted seven treatment combinations as follows; 1) Control, no organic residue application; 2) 10 ton/ha compost, surface application; 3) 10 ton/ha compost, incorporated application; 4) 5 ton/ha maize stover, surface application; 5) 5 ton/ha maize stover, incorporated application; 6) 5 ton/ha maize stover, 10 ton/ha compost, surface application; 7) 5ton/ha Maize stover, 10 ton/ha compost, incorporated application). The seven treatments were laid out in a randomized complete block (RCBD) design with 3 replications. Soil samples were collected from 0-20cm and 20-40cm depths before planting, at six weeks after planting and at harvest. The soil samples were analyzed for total C, total N, soil pH, available P, Mg, Ca, Na, K and CEC. Maize grain yield and total dry matter was measured. Statistical analysis of data was done using analysis of variance (ANOVA) and means separated using LSD at p=0.05. Results of this study showed that total soil organic carbon increased with application of organic residues. Treatments that had 5ton/ha maize stover and 10 ton/ha compost, incorporated recorded the highest soil carbon accumulation of 0.36 Mg C/ha and 0.39 Mg C/ha at the end of season one and two, respectively while the control decreased by 0.02 Mg C/ha in season 1 and 0.03 Mg C/ha in season two. Nutrients concentrations in the soil were found to increase with application of organic residues where by incorporated 5 ton/ha maize stover and 10 ton/ha compost treatment recorded the highest concentrations of most nutrients in the soil. Maize yields increased with the application of organic residues. Treatments that had 5 ton/ha maize stover and 10 ton/ha compost under incorporated application gave the highest maize grains which was 145% more, compared to the control in season one and 248% in season two. In conclusion combining 5 ton/ha maize stover and 10 ton/ha compost under incorporated application could be a promising soil fertility management strategy for improved carbon storage in soils and for increased maize productivity.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Food insecurity is a central concern and a fundamental challenge for human welfare and economic growth in Africa. Land degradation and soil fertility depletion are considered the major threats to food security and natural resource conservation in sub-Saharan Africa (SSA) (Smaling et al., 1997). The area of degraded soils is extensive and the effects of degradation are evident in many parts within Africa, which are characterized by degradation-prone soils, and unsustainable intensification particularly in many of the densely populated zones (Scherr, 1999). This has caused per capita food production in Africa to decline over the past two decades, contrary to the global trend. The growth rate for cereal grain yield, which constitutes 90% of food intake in SSA, is about 1%, while population growth is about 3% (Smaling et al., 1997).

Due to rapid increase in population, there is need to urgently address the challenges of food insecurity as well as climate change especially in sub-Saharan Africa and the developing world. Atmospheric concentration of CO_2 has increased from about 280ppm in pre-industrial era to about 385ppm in 2008(+37.5%) and is presently increasing at the rate of about 2ppm/year (Lal, 2009). Much of the CO_2 concentration in the atmosphere is due to emission by human activity, which is attributed to fossil fuel combustion, deforestation and biomass burning, soil cultivation and drainage of wetlands or peat soils (Lal, 2009). The increase in CO_2 concentration in the atmosphere is associated with an elevation in global temperature (global warming) which has potential disastrous consequences.

The use of organic matter in integrated soil fertility management is inevitable. Application of organic manures and organic wastes to agricultural soils is necessary so as to supply nutrients to crops, to increase or at least maintain organic matter content in soil and to recycle materials for protection of the environment (Smith, 2004).There is a potential to store C in the terrestrial ecosystems. Increased soil carbon storage through improved manure management can reduce CH_4 emissions by composting organic wastes and hence improve crop yields (IPCC, 2007). Attention is being put to the potential of soils to act as C sinks. This is being reflected in the emphasis to determine turnover rates, sizes and composition of different C pools and in developing hypotheses addressing the mechanisms involved in C stabilization (Kleber et al., 2007).

The UN Intergovernmental panel on climate change (2001) recognizes the possibility of carbon sequestration "using biospheric processes to remove C from the atmosphere and transport it to the deep ocean", but potential of the terrestrial sink has apparently been overlooked (Neal et al., 2013). Estimates of carbon stocks within different land management and cropping systems are an important element in the design of land use systems that sequester carbon (Bationo et al, 2007). Limited studies in small-hold agricultural farms in Africa have already illustrated significant increase in system carbon and productivity through organic resource management (Roose and Barthes, 2001).

1.2 Problem Statement

Declining crop productivity in Arid and Semi-arid areas (ASALs) is attributed to low and erratic rainfall, declining soil fertility, land degradation, and climate variability.(Bationo et al., 2007). Consequently, the present farming systems are not sustainable (Bationo and Buerkert, 2001).Climate change is a major concern to most researchers in the world. The concentration of CO_2 in the atmosphere continues to rise (Lal, 2009). Increase in CO_2 in the atmosphere is a major contributor to global warming and climate change. Increased CO_2 release from decomposing OM can be reduced through increased C-storage in the soil. Many studies have been conducted with respect to organic residues but very little has been done to show how organic materials can be used to store C in the soil. Empirical data on the relationship between organic residues and carbon storage in the soil is thus scanty. The purpose of this study was therefore to investigate the effects of organic residue incorporation on soil carbon, selected nutrients and maize yields.

1.3 Justification of the Study

In the past few decades significant changes in climate and land use have caused soil organic carbon depletion leading to a declining trend in productivity (Martin et al., 2010). Rise in temperature and change in land use have significantly reduced soil organic carbon content in soils. According to Shrestha et al., (2004) rise in temperature enhances the rate of soil respiration, thereby increasing mineralization of soil organic carbon (SOC) and the chances of carbon loss from soil to atmosphere as CO_2.

This study sought to create awareness on the possibility to sequester C in the soil by incorporating organic residues into the soil and hence reduce adverse effects of carbon dioxide in the atmosphere. The study also provides some insight information to the small-holder farmers in Katumani on the need to use organic resources to replenish soil fertility and increase maizeyields.

1.4 Broad Objective

The broad objective of this study was to investigate soil carbon sequestration, nutrient availability in the soil and maize yields improvement through use of organic residues under different application methods.

1.4.1 Specific Objectives

1. To determine the effect of organic residues and placement method on carbon sequestration in the soil.
2. To determine the effect of organic residues on the availability of nutrients in the soil.
3. To determine the effect of different organic residues on maize growth and yields.

1.5 Hypotheses

1. Application of organic residues significantly increases soil carbon sequestration.
2. Application of organic residues enhances nutrient availability in the soil.
3. Application of organic residues significantly increases maize yields.

1.6 Significance of the study

The findings of this study can be utilized by extension service providers, researchers and farmers in the design of programs and projects, which can facilitate adoption of soil and environment conservation practices and hence lead to increased crop yields.

1.7 Conceptual framework

The conceptual framework shows the relationship between climate variability and declining soil fertility, and the interventions which were undertaken in this study to improve soil fertility and hence increase maize yields.

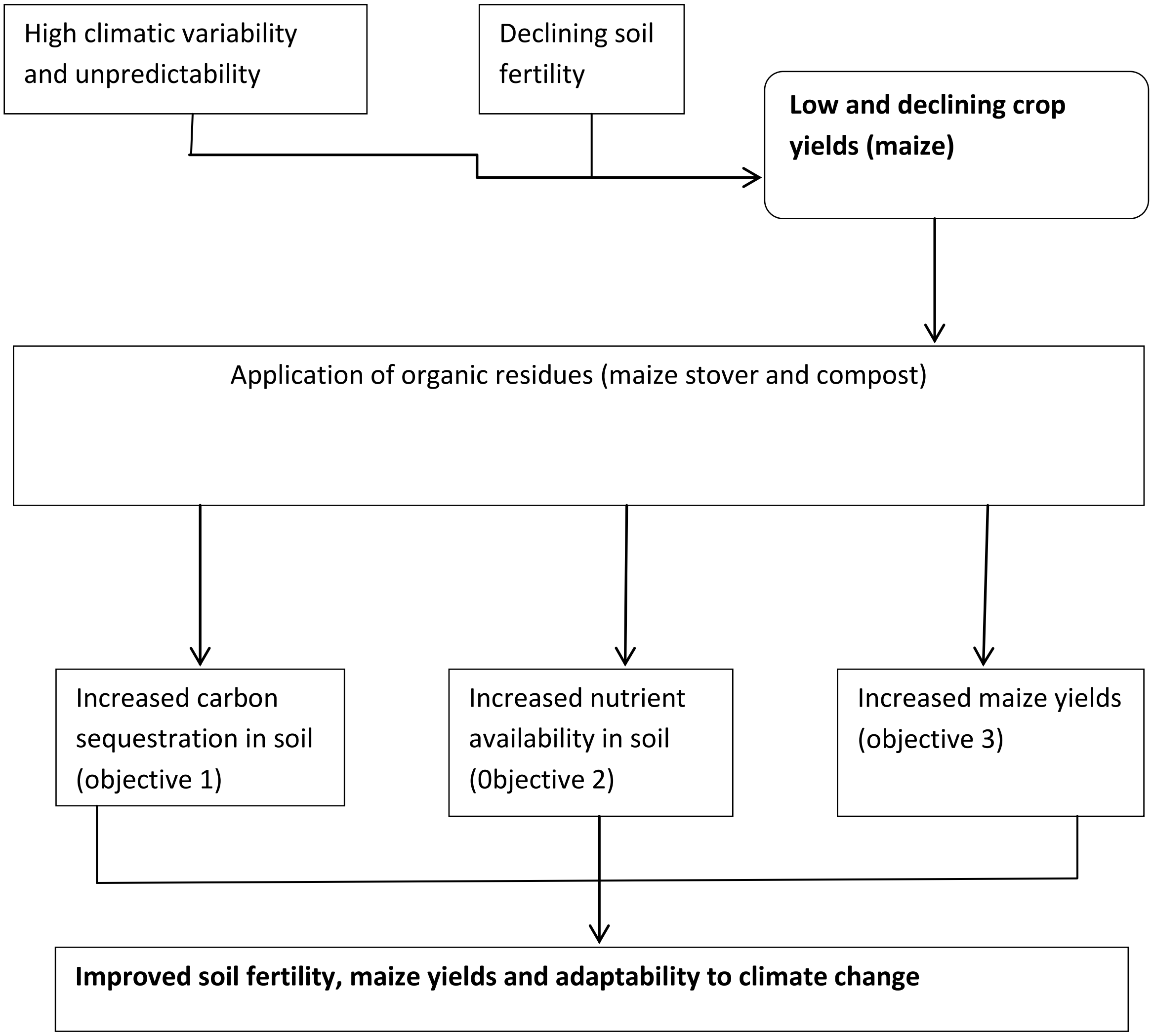

Figure 1: Conceptual framework of the study

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Land degradation and soil fertility depletion are considered the major threats to food security and natural resource conservation in sub- Saharan Africa (SSA). The area under degraded soils is extensive and the effects of degradation are evident in many parts within Africa, which are characterized with degradation-prone soils(Scherr, 1999). Use of organic residues can greatly reduce the effects of soil degradation since organic resources play an important role for soil fertility improvement in sub-Saharan Africa, i.e. through short-term nutrient supply and long-term soil quality improvement by the build-up of soil organic matter (SOM) (Chivenge et al., 2011).

2.2 Role of organic matter in soil fertility management

Soil organic matter is important in terms of soil fertility, sustainable agricultural systems, and crop productivity, and there is concern about the level of organic matter in many soils, particularly with respect to global warming (Edward et al., 2009). The amount of organic matter in soil depends on the input of organic material, its rate of decomposition, the rate at which existing soil organic matter is mineralized, soil texture, and climate. All four factors interact so that the amount of soil organic matter changes, often slowly, toward an equilibrium value specific to the soil type and farming system (Edward et al., 2009). Soil fertility is closely linked to soil organic matter, whose status depends on biomass input and management, mineralization, leaching and erosion (Roose and Barthes, 2001).Soil management practices that produce optimal grain yields while preserving the ecosystemservices of agricultural systems are essential in the face of climate variability (Mekuria, 2012).

Soil organic matter (SOM) has many functions, the relative importance of which differs with soil type, climate, and land use. Commonly the most important function of OM in soil is as a reserve of the nitrogen and other nutrients required by plants, and ultimately by the human population. Other important functions include: the formation of stable aggregates and soil surface protection; maintenance of the vast array of biological functions, including the immobilization and release of nutrients; provision of ion exchange capacity; and storage of terrestrial carbon (Craswell and Lefroy, 2001).The use of organic resources has achieved significant strides in improving soil fertility in many agro ecological zones in SSA. Balanced fertilization of soils through synchronized supply of adequate nutrients to growing crops as well as increasing soil organic matter content over the long term are major gains realized through application of organic resources (Omotayo and Chukwuka, 2009). Organic residues are also very important in improving the physical, chemical and biological properties of the soil (Sodhi et al., 2009). In the longer term, continuous application of organic inputs may improve soil physical and chemical characteristics such as soil structure, bulk density, porosity, and nutrient retention among others, and consequently lead to better crop growth (Vanlauwe et al., 2001).

2.3 Role of organic residues in soil carbonsequestration

The use of organic matter (OM) amendments is widespread in tropical countries and may be beneficial for soil carbon sequestration (Ngo et al., 2012).The role of soil organic matter (SOM) in agricultural systems has been widely studied in conjunction with the potential for greenhouse gas mitigation. However, the link between SOM accumulation in croplands, crop productivity and yield stability has not yet been clearly established (Pan et al., 2009). In order to manage the soil resource effectively there is need for optimum management of organic resources and soil organic carbon (SOC) pool (Vanlauwe, 2004). Soil organic carbon is an important component of the agro-ecosystem because of its role in the dynamics of greenhouse gases (Kirschbaum, 2000). SOC plays an important role and its maintenance is an effective mechanism to combat land degradation and increase future food production (Bationoet al., 2007).

It is reported that about one fourth of anthropogenic carbon dioxide emissions are due to land use change, especially deforestation, and the rest is due to fossil burning in the past 20 years (Barnett et al., 2005). Long-term experimental studies have confirmed that soil organic carbon is highly sensitive to land use changes from native ecosystems, such as forest or grassland, to agricultural systems, resulting in loss of organic carbon. Changes in land use and vegetation also cause carbon depletion by influencing soil respiration and carbon fluxes in soil (Post and Kwon, 2000).Management of soils to increase SOC levels can therefore increase the productivity and sustainability of agricultural systems. A significant correlation between SOM and cereal productivity in China was reported (Pan et al., 2009). The study suggested that enhancing carbon sequestration in croplands enhances crop productivity and stabilize yields, which offers a sound basis for greenhouse gases (GHGs) mitigation. Such crop management increases the capacity to store more organic carbon in soil.Chivenge et al., (2011) in a study conducted in Embu, Kenya reported an increase in carbon sequestration in soil with application of organic residues. Neal et al., (2013) in a study conducted in Australia also reported increased carbon sequestration in the soil with addition of organic residues.

2.4 Soil carbon sequestration and climate change mitigation

Presently, considerable attention is given to the potential of soils to act as C sinks (Knicker 2011). According to Martin et al., (2010), in the past few decades significant changes in climate and land use have caused soil organic carbon (SOC) depletion leading to a declining trend in productivity. Since a long time, mineral fertilizers have been widely used to increase crop yields all over the world (Ngo et al., 2012). Numerous studies have shown that their use can have many negative effects on soil such as acidification, increased leaching losses, decline of organic matter (OM) content and reduction of microbial communities (Marschner, 2002).

Whereas the effect of organic amendments on plant growth and yields are well documented, less is known about its impact on carbon sequestration in agricultural soils. According to Ngo et al., (2012), a study conducted on the tropical soils reported increased carbon sequestration on soils amended with organic residues like compost compared to initial soil, or even compared to soil amended with chemical fertilizers. According to Prentice (2001) and Lal (2004b), increasing carbon sequestration in soils is one option helping tomitigate increasing atmospheric CO_2concentrations and global climate change. The potential of agricultural land to mitigate greenhouse gases and sequester C may be an added benefit of maintaining soil fertility levels through the use of best management practices (Fortuna et al., 2003).The sequestration of atmospheric carbon dioxide into soil organic carbon (SOC) to mitigate greenhouse gas emissions may become an important farm management strategy in the future (Neal et al., 2013). According to Neal et al., (2013) there is limited data available on the potential of organics to sequester soil organic carbon under best practice management.

2.5 Soil C-N transformations and Organic residues

The impact of organic resource quality on Soil Organic Carbon (SOC) is less clear (Bationo et al., 2007). Low quality organic resources contain substantial amounts of soluble polyphenols and lignin that contribute to the buildup of SOC (Palm et al., 2001). Future research needs to focus more on whether the organic resource quality concept is also useful for predicting different degrees of stabilization of applied organic C in one or more of the organic matter pools (Bationo et al., 2007).The availability of soil organic nitrogen(SON) determines soil fertility and biomass production. SON also affects the amounts and turnover rates of the SOC pools. Although there is increasing awareness of the impact of the nitrogen(N) cycle on the carbon(C) cycle, the extent of this interaction and the implications for soil organic matter (SOM) dynamics are still under debate (Knicker, 2011).

Presently, considerable attention is given to the potential of soils to act as C sinks. This is reflected in the emphasis to determine turnover rates, sizes and composition of different C pools and also in developing and elucidation of hypotheses addressing the mechanisms involved in C stabilization (Kleber et al., 2007). SON and SOC are closely coupled in biomass production and degradation and as such nitrogen has a major impact on the global C and N-cycling (Gardenas et al., 2011).Nitrogen (N) is a major nutrient element controlling the cycling of organic matter in the biosphere. Availability and concentration of N in both its organic and inorganic forms is closely related to biological productivity in terrestrial and aquatic systems.

Nitrogen availability is related to changes in the amount of C immobilized into newly formed biomass, which subsequently affects both size and quality of the SOM

pools (Knicker, 2011). Soil N is not a static entity, but takes part in a series of interconnected reactions that constitute the N cycle. This cycle is determined by the competition for this nutrient between plants, fungi and soil bacteria. Additionally, a part of the N is sequestered by its transformation and incorporation into biologically refractory organic material(Knicker, 2011). The pathways of this incorporation, however, are still not understood and subject of ongoing debate(Knicker, 2004; Rillig et al., 2007; Colman et al., 2008; Davidson et al., 2008; Thorn and Cox, 2009).

2.6 Organic resources and nutrient availability in soil

According to Adjei-Nsiah, 2012 incorporation of organic residues into the soil helps in accumulation of quite substantial amount of nitrogen into the soil system. Organic residues which undergo faster decomposition (e.g. chickpeas, dolichos, cassava and pigeon pea) release nitrogen faster compared to those that undergo slower decomposition like maize stover. This leads to better synchrony with maize demand than the slower release of nitrogen by the poorer quality materials like maize stover. The N release patterns of organic residues of differential quality have been discussed extensively by Danga et al., 2009. Poor quality organic residues with high C: N ratio provides abundant supply of C for microbial growth leading to immobilization of soil N in the microbial biomass (Danga et al., 2009). Residues of high quality organic inputs on the other hand decompose quickly and may release between 70% of the N within a season under tropical conditions (Giller and Cadisch, 1995).

Application of organic residues has a fertilizing effect on agricultural soils (Hargreaves et al., 2008).Given that part of the nutrients are present in organic forms, the gradual release of plant nutrients after mineralization is another of the expected advantages of the use of organic amendments (Frossard et al., 2002 and He et al., 2005). Although the effect of organic residues on the concentration, availability and dynamics of soil N and P has been widely studied, studies evaluating the effect on Ca, Mg, and K are still scarce. Most existing literature does not report the evolution of those nutrients throughout the short period following organic residue addition. However, this point deserves more attention because, if the mineralization process is responsible for the gradual release of nutrients from organic resources, their concentrations should increase after organic residues addition (Paradelo et al., 2012).

2.7 Organic resources application and maize yields

Organic residues can increase maize yields more than or similar to application of inorganic fertilizers (Nziguheba et al., 2000). The increase in yields is associated with increased nutrient uptake and also mulching effects (Tian et al., 1993). The yield response to organic residues is dependent on the amount of OM, quality of organic residues and method of application (Mutegi et al., 2012). Organic inputs can alleviate constraints to crop growth other than N depletion and, as such, improve the use efficiency of N fertilizer (Vanlauwe et al., 2001). Organic residues which undergo rapid mineralization produce higher grain yield and stover in maize as compared to those organic residues which undergo slow mineralization during early stages of maize growth (Nyongesa et al., 2009). Organic residues can either be surface applied or incorporated.

Differences in maize yield between surface applied and incorporated organic inputs is not significant, according to (Vanlauwe et al., 2001). Incorporating organic residue is more likely to be beneficial in the long run. In the longer term, continuous application of organic inputs may improve soil physical and chemical characteristics such as soil structure, bulk density, porosity, and nutrient retention among others, and consequently lead to better crop growth (Vanlauwe et al., 2001). Many studies have shown that organic amendments can increase maize yields and other crops significantly (Marschner 2002; Hepperly et al., 2009; and Mekuria 2012).

2.8 Comparison between organic fertilization and inorganic fertilization

According to Ngo et al., (2012), mineral fertilizers have been widely used for a long time to increase crop yields all over the world. The uniformity, low labourcost and ease of application associated with inorganic fertilizers are some of the qualities preferred over the use of organic nutrient sources (Fortuna et al., 2003). However many studies have shown that the use of mineral fertilizers can have many negative effects on soil such as acidification, increased leaching losses, decline of organic matter (OM) content and reduction of microbial communities (Marschner, 2002; Ebid et al., 2007; Adjei-Nsiah, 2012; Ngo et al., 2012). An alternative to mineral fertilization is the amendment of soil with organic matter. Composting organic materials has the advantage to stabilize and to homogenize them (Ngo et al., 2012). Organic residue addition has been shown to improve soil fertility (Cantanazaro et al., 1998 and Caravaca et al., 2002); plant nutrition and vegetation cover (Larchevêque et al., 2005). However, it can improve other soil functions such as soil hydraulic conductivity (Celik et al., 2004), aggregate stability and resistance to erosion (Bresson et al., 2001). Organic residues addition also helps in reducing nutrient losses through leaching and also improves soil organic matter content. Hepperly et al., (2009) observed that addition of organic residues like compost supported both high yields and increased soil C and N content, while synthetic chemical fertilizer produced only high yields but did little or nothing to improve soil nutrient content. Organic residue amendments have long term advantages of soil improvements while over short-term and medium-term use, synthetic chemical fertilizers are attractive due to their convenience, ease of application, and reliable high yield. Hepperly et al., (2009) reported that although synthetic chemical fertilization is able to stimulate high short-term yields, it will not be able to support sustainable crop productivity, crop health, or soil health over longer time periods. He further reported that the greatest disadvantage of synthetic chemical fertilizer use, is its effects on soil N and C levels, which do not improve, and in some cases decline with its use, while use of organic residues increased both soil C and N levels, making it clearly superior to chemical fertilizer in terms of long term sustainability and productivity. However other studies have shown that combining both the organic residues and inorganic residues to be more advantageous in terms of nutrient synchrony and soil fertility improvement hence increased yields (Sakala et al., 2000; Vanlauwe et al., 2001; Nyamangara et al., 2003; Mugwe et al., 2008; Nyongesa et al., 2009; Laekemariam and Gidago, 2012).

2.9 Summary and Research gaps

Despite the availability of all the above literature, the effectiveness of usage of organic residues in order to sequester carbon in the soil and hence mitigate climate change has not been fully documented. Many studies have been done to assess the effect of combining organic and inorganic resources to improve productivity in semi-arid soil, but very little literature exists on sole application of organic resources. In this study, pure organic residues (compost and maize stover) were used either sole or in combination in order to assess their possibilities of being used in carbon sequestration to mitigate climate change, improve soil fertility and also improve maize production.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The study was conducted at Kenya Agricultural Research Institute (KARI) – Katumani(1º35'S: 37º14'E) in Machakos County. The area is located at the semi- arid zones of Eastern Kenya. The site has bimodal rainfall which is low and erratic. The short rains occur in October to January (250-350 mm) and the long rains in March to June (350-700 mm). In the past, the pattern used to be consistent but these days it is very unpredictable probably due to climate change effect. The humidity is relatively high with mean evaporation being between 1800 mm to 2000 mm in a year. Temperatures also vary with altitude. The mean minimum temperature is 13.7°C while the mean maximum temperature is 25°C (Mochoge and Danga, 2010). Soils are sandy loam with low clay contents. Soil organic carbon is low <1% while total N is also low ranging below 0.1% (Mochoge and Danga, 2010). The soils have been classified as Luvisols according to FAO- UNESCO system of soil classification.

3.2 The experimental treatments and design

A field experiment was conducted for 2 seasons at KARI, Katumani, situated in semi-arid Machakos to explore the effects of two types of organic manures (compost and maize residues), under two different application methods (surface and incorporated). Compost was applied at 10 ton/ha and maize residues at 5 ton/ha. These gave a total of 7 treatments as follows;

1) Control (no organic residue application),

2) 10 ton/ha compost (Surface application),

3) 10 ton/ha compost (Incorporated application),

4) 5 ton/ha maize stover (Surface application),

5) 5 ton/ha maize stover (Incorporated application),

6) 5 ton/ha maize stover, 10 ton/ha compost (Surface application),

7) 5 ton/ha maize stover, 10 ton/ha compost (Incorporated application).

The 7 experimental treatments were arranged in a Randomized Complete Block Design (RCBD) with three replicationsgiving a total of 21 plots. Each plot was 5m by 4m totaling to 20m^2 per plot. The net plot was 6 m^2 after leaving out 1 m by each side during harvesting to avoid border effect. The experiment was conducted in two seasons (2011/2012 short rains and 2012 long rains). Blocking was done according to slope due to elevation of the site.

3.3 Soil sampling

Soil sampling in season one, was carried out before the experiment was established in October 2011, six weeks after planting in November 2011 and immediately after harvest of season one in March 2012. Another sampling for season two was done six weeks after planting of season two in May 2012 and after harvest in August 2012. Soil samples were collected on diagonal transect from each plot. Samples from three different points were bulked to give a composite sample at depths; 0-20 cm and 20-40 cm using soil auger. The soil samples were analyzed for the following parameters; total C, total N, soil pH, available P, Mg, Ca, Na, K and CEC

3.4 Laboratory analysis

3.4.1 Soil pH (water)

Twenty grams of air-dry sieved (2mm) soil was weighed into 100 ml plastic bottles. Fifty ml of distilled water was added then shaken on an electric shaker for 30 minutes. The contents were then allowed to stand for 10 minutes. The pH of the soil suspension was then measured using a pH meter. Before any measurements were done the pH meter was standardized using buffer pH 7 and pH 4. This was according to the procedures outlined in (Okalebo et al., 2002).

3.4.2 Total Organic carbon and nitrogen

Determination of the total organic carbon and nitrogen was done using the flash combustion method using Thermo Scientific Flash 2000 Elemental Analyzer; The CN Analyzer (Krotz et al., 2000).The soil was ground for homogeneity until an optimum granularity of 100-200 µm was reached. Twenty mg of soil were carefully weighed using a microbalance. Weighing was done into tin capsules and folding done using forceps. After folding the sample was weighed and the correct weight recorded. The weighed sample was then placed on a microtitre plate rack which was then transferred to the auto sampler in the CN Analyzer machine. The percent carbon and nitrogen content in the samples were then read from CN Analyzer machine in terms of percentage.

3.4.3 Exchangeable Calcium, Potassium and Sodium

Five g of air-dried soil was weighed in a 50 ml polythene bottle. One scoop (0.5) g of activated charcoal and 25 ml extracting solution was added. Extracting solution was a mixture of 0.1N HCl and 0.025N H_2SO_4. Twenty five ml stock extracting solution was diluted in 900 ml distilled water (DW) and filled up to the 1 litre mark and mixed well. The contents were then shaken mechanically for 1 hour at room temperature at 220 revolutions per minute using a mechanical shaker. The suspension was then filtered through whatman No.1 filter paper. A blank and an internal reference sample were included in each series. Two ml of working standard series, soil extract and blank were pipetted into 25ml vials. One ml of 2% lanthanum chloride and 14ml DW, was added and shaken by hand, then allowed to stand overnight. The working standard series, soil extract and blank solutions were aspirated into the flame photometer and transmission recorded. Samples giving higher concentration than the highest standard were diluted using the extracting solution. Calibration graphs of transmissions of working standard series against elements' (Ca, K, and Na) concentrations (in me/100 g soil) were obtained. Concentrations of the samples were read from those graphs. Corrections for reagent blank were made by subtracting the blank value from sample concentration value. Where there was any dilution, the corrected concentration was multiplied by the dilution factor (Chapman, 1965 and Okalebo et al., 2002).

3.4.4 Exchangeable Magnesium

The soil was extracted as extracted as above in calcium, potassium and sodium determination. One ml of working standard series, soil extract and blank were pipetted into test tubes. Five ml of magnesium compensating solution was added; 2 ml titan yellow and 2 ml sodium hydroxide were also added, mixing after each addition. The optical density was read on the u-v visible spectrophotometer after one hour at 540 nm. Corrections were made by subtracting the blank value from the sample concentration value. This was according to (Bolland et al., 2003).

3.4.5 Available Phosphorus

Available phosphorus was determined using the vanadium yellow method after extraction according to Mehlich method (Mehlich, 1984). The soil was extracted as

extracted as above in section 3.4.4. Then 5ml of the filtered extractant was pipetted into a clean test-tube. One ml of ammonium vanadate and ammonium molybdate solution mixture was added. The colour was left to develop for 20 minutes and the colour density or absorbance read at wavelength 430nm using the u-v visible spectrophotometer. The concentrations of standards solution against the colour density or absorbance reading were plotted. The concentration of available soil phosphorus in the soil extract as read from the standard curve was converted into ppm p in the soil by multiplying by 25/5 i.e. 5. This represents the ratio of the extracting solution to soil.

3.4.6 Cation exchange capacity (CEC)

This was done according to the procedure outlined in (Okalebo et al., 2002). Ten (10) grams of air-dried soil ground to less than 2mm was weighed into a 250 ml beaker. Twenty five ml of NH_4OAc was added to the soil. It was then covered and left to stand overnight. For each sample, a 7 cm Buchner funnel was prepared by fitting it with a 7cm whatman No.1 filter paper. The filter was made wet with a minimum amount of NH_4OAc. Then the funnel was inserted into a 250 ml suction flask and vacuum pump turned on to seat the moistened filter. The soil-NH_4OAc mixture was stirred and transferred into the filter. Approximately 75 ml of NH_4OAc was measured for each sample into a plastic squirt bottle with one bottle for each sample. About 10 ml of the NH_4OAc in the bottle was used to transfer all of the soil to the Buchner funnel. The soil was covered with a 7.0 cm whatman No.1 filter paper to keep the soil moist between the leachings. The soil was leached 5 to 7 times with 10 to 15 increments of NH_4OAc without letting the soil dry between the leachings. To remove excess NH_4OAc in the soil, the soil was leached with ethanol with about 25 ml portions of ethanol five to six times for a total volume of about 150 ml.To remove adsorbed NH_4 in the soil, the soil was leached with 1 M KCl with about 25 ml portions of 1 M KCl four to five times for a total volume of about 125 ml. The leachate was transferred to a 250 ml volumetric flask and brought to volume using 1MKCl. The solution was analyzed for NH_4 concentration (mg/L). Then CEC was determined using the following formula:

$$\text{CEC (cmol/kg)} = NH_4\text{-N (mg/L)} \div 14$$

$$(NH_4\text{-N in extract} - NH_4\text{-N in blank})$$

3.5 Field establishment and management

3.5.1 Land preparation and planting

The land was prepared by digging with plain hoe; big clods were broken and harrowing done so as to get a fine tilth. The test crop was maize (*Zea mays L.,* Duma-43 variety). The maize was planted at a spacing of 30 cm x 75 cm. Weeding was done using a plain hoe in all plots, except on the plots where surface application was done where by weeding was done by hand picking. Pests and disease management was done using appropriate chemicals.

3.5.2 Organic residues application

Organic residues were weighed for each plot;application of organic residues was done differently. Incorporation of maize stoverwas done two weeks before planting while compost incorporation was done during planting (incorporate at seeding) manually with a hoe. Both maize stover and compost under surface application was done after planting.

Table 1: Chemical characteristics of the organic inputs used

Residue	Total C%	Total N%	C/N ratio	P%	Ca%	Mg%	K%
Compost	21.10	1.75	12	2.13	8.58	0.16	4.08
Maize stover	43	1.05	40	0.05	0.26	0.10	0.83

3.6 Soil properties before treatment application

The soil was weakly acidic with pH ranging between 5.93- 6.17 (Table 2). Total nitrogen and carbon were relatively low with total carbon ranging between 0.37%C - 1.03%C, and total nitrogen ranging between 0.04% N to 0.11% N (Table 2). The concentrations of the exchangeable bases i.e. P, K, Na, Ca, and Mg were also relatively low (Table 3). Cation exchange capacity of the soil was low ranging between 2.40 – 3.06 cmol/kg (Table 3).

Table 2: Soil chemical properties before treatment applications at the depths 0 - 20 cm and 20 - 40 cm in October 2011

Treatment	pH (water)		%C		%N		P (mg/Kg)		K (cmol+/kg)	
Depth (cm)	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
CTRL	6.12	5.98	1.00	0.37	0.09	0.04	11.00	6.33	1.02	0.59
CS	6.12	5.98	1.00	0.37	0.11	0.04	10.33	5.33	1.02	0.57
CI	6.17	5.93	0.97	0.37	0.10	0.05	11.67	6.33	1.02	0.58
MS	6.13	6.00	0.97	0.37	0.10	0.05	10.00	6.67	1.03	0.57
MI	6.17	6.02	1.03	0.43	0.09	0.05	12.00	5.67	1.02	0.58
MCS	6.11	6.01	0.90	0.40	0.10	0.04	11.67	4.67	1.03	0.58
MCI	6.14	5.98	1.00	0.40	0.10	0.05	12.00	6.33	1.02	0.59
SED	**0.05**	**0.05**	**0.06**	**0.07**	**0.016**	**0.09**	**0.87**	**0.84**	**0.02**	**0.01**
LSD	**0.098**	**0.105**	**0.132**	**0.158**	**0.034**	**0.019**	**1.87**	**1.79**	**0.02**	**0.02**
P value	**0.741**	**0.618**	**0.495**	**0.949**	**0.858**	**0.854**	**0.188**	**0.263**	**0.942**	**0.507**

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated).

Table 3: Exchangeable cations and Cation Exchange capacity of soil sampled before treatment applications at the depths 0 - 20 cm and 20 - 40 cm in October 2011

Treatment	Ca (me %)		Na (mg/Kg)		Mg (me %)		CEC (cmol/kg)	
Depth (cm)	0 – 20	20 – 40	0 – 20	20 – 40	0 – 20	20 – 40	0 – 20	20 – 40
CTRL	2.63	1.63	22.13	21.00	1.46	2.13	3.06	2.40
CS	2.63	1.63	23.43	20.33	1.47	2.12	2.99	2.46
CI	2.47	1.47	23.33	21.00	1.47	2.13	3.02	2.45
MS	2.63	1.63	22.93	20.97	1.47	2.13	3.04	2.43
MI	2.77	1.77	23.40	21.43	1.47	2.13	3.13	2.46
MCS	2.60	1.60	23.80	20.23	1.49	2.12	2.97	2.37
MCI	2.63	1.63	22.50	21.13	1.47	2.13	3.04	2.51
SED	**0.02**	**0.12**	**1.02**	**0.34**	**0.015**	**0.01**	**0.07**	**0.06**
LSD	**0.37**	**0.25**	**2.19**	**0.73**	**0.033**	**0.02**	**0.15**	**0.12**
P value	**0.258**	**0.385**	**0.685**	**0.082**	**0.659**	**0.882**	**0.406**	**0.294**

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated).

3.7 Maize plant height

Maize plant heights were taken at 6 (six) weeks after planting for both seasons and also at full maturity i.e. during harvesting during both the 2011/2012 short rains and also during the 2012 long rains season. The height of every 4th maize plant was taken systematically leaving out the guard rows in all the plots.

3.8 Maize harvesting

Grain and biomass harvesting was done manually and weighing done using a weighing balance. The maize was harvested by cutting at the root collar. It was immediately weighed to determine total fresh weight (stover + unshelled cobs). The unshelled cobs were then separated from the stover. The total fresh weight of the stover was determined and a sub-sample taken for dry weight determination. To obtain grain yields, grains were separated from the core by hand shelling, weighed, and a sub-sample taken for dry weight determination. Similarly, empty cobs (without grains) were weighed and a sub-sample taken for dry weight determination. To determine dry weight, the above sub-samples (cobs, stover and grain) were oven dried at $60^{o}C$ for three days to a constant weight. After harvesting in season one, all the maize stovers were removed from the experimental plots to ensure that they did not return any nutrients to the experimental plots which could affect season 2 experiment. To convert the yields to international standards the calculations were done as follows:

Corrected grain wt. (g)/net plot (m^2) × 10000/10000 = Grain weight in Mg Ha^{-1}

Corrected grain wt. (g) = FW × (% STM/ % MF)

Where; FW – Field grain weight,

% STM - % standard moisture required (12.5%)

% MF - % moisture measured in the field

3.9 Specific methods as per the objectives

3.9.1 Effect of organic residue source and placement on carbon sequestration in soil

Soil samples were collected from the treatment plots before planting (baseline) and after harvest of both season one and season two, and analyzed for total carbon. The difference in C was determined by subtracting C values obtained at harvest from the baseline values. Percent carbon change was converted to Mg C/ha to determine the amount of C sequestered using the following formula.

Tonnes per hectare carbon = SOC % * Bulk density (Mg/m^3) * Sampling depth (m).

In order to determine the amount of carbon sequestered in the maize plants as a result of different treatment applications, the %C in the total biomass after harvest was measured and conversions made according to the yields obtained in each treatment i.e.

Carbon sequestered in maize plants (Mg/ha) = %C*total above ground biomass.

3.9.2 Effect of organic residue sources and placement on nutrient availability

To investigate how various organic residues and their placement led to accumulation of various nutrients into the soil, soil samples before seeding were analyzed for total N, available P, extractable K, and cationexchangecapacity (CEC). Further soil sampling was done six weeks after planting (seedling stage)in both the two seasons.

3.9.3 Effect of different organic residues on maize growth and yields

Maize yields were collected at full maturity. Plant biomass and maize grains produced were weighed using a weighing balance. This was used to investigate whether there was any increase in maize yield under different organic residues application. Since plant height is an important parameter in determining the final plant yields, maize plants heights were taken six weeks after planting and also at harvest.

3.10 Statistical data analysis

Genstat 14th edition computer package was used for statistical analysis. Treatment effects on soil total carbon, nitrogen, available phosphorus, potassium, exchangeable cations, cation exchange capacity, maize yields and maize plant height were analyzed using analysis of variance (ANOVA). Treatment means found to be significantly different from each other were separated by Least Significant Differences (LSD) at $P < 0.05$. T- tests for the pairwise comparison of the seasons and the baseline data was done at $P = 0.05$.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Effect of organic residues application on carbon sequestration

4.1.1 Effect of treatments on soil carbon sequestration

Application of organic residues significantly increased ($P<0.05$) carbon sequestration in the soil at the depth of 0-20 cm (Table 4).Percent carbon in the soil was higher in the second season than the first season in all the treatments except in the control. This showed that carbon sequestration in the soil increased with continued application of organic residues.

Table 4: Changes in soil organic carbon content for two seasons (2011/2012 short rains and 2012 long rains) at the depth of 0-20 cm

Treatment	**Season 1**				**Season 2**			
	BSL (% C)	S1 (% C)	Change (% C)	t-test p value	BSL (% C)	S2 (% C)	Change (% C)	t- test p value
CTRL	1.00	0.93d	-0.07	0.184	1.00	0.90d	-0.10	0.225
CS	0.97	1.23c	0.26	0.094	0.97	1.40c	0.43	0.006*
CI	1.03	1.37c	0.34	0.038*	1.03	1.50c	0.47	0.005*
MS	1.00	1.63b	0.63	0.002*	1.00	1.77b	0.77	0.011*
MI	0.97	1.67b	0.70	0.029*	0.97	1.80b	0.83	0.007*
MCS	0.90	2.10a	1.20	0.002*	0.90	2.27a	1.37	0.002*
MCI	1.00	2.27a	1.27	0.005*	1.00	2.40a	1.40	0.012*
SED	**0.062**	**0.093**	**-**	**-**	**0.062**	**0.130**	**-**	**-**
LSD$_{(0.05)}$	**0.158**	**0.198**	**-**	**-**	**0.158**	**0.278**	**-**	**-**
pValue$_{(0.05)}$	**0.495**	**<0.001**	**-**	**-**	**0.495**	**<0.001**	**-**	**-**

Means with different letter(s) along the same column are statistically different at P= 0.05

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), S1- (end of season 1), S2- (end of season 2), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

At the end of season 1, significant change in the total carbon in the soil from the baseline was recorded (Table 4). Application of organic residues increased the organic carbon in all the treatments while in the control the carbon decreased. The highest carbon sequestration was recorded in the combination of maize stover and compost under incorporated application (MCI) which increased by 1.27 %, an equivalent of 0.36 Mg C/ha (Appendix 2). This treatment was followed by a combination of maize stover and compost under surface application (MCS) with an increase of 1.2 % which was equivalent to 0.34 Mg C/ha. The carbon content in the control treatment decreased by 0.07 % which was equivalent to 0.02 Mg C/ha.

At the end of season 2 there was a significant change in the organic carbon in the soil from the baseline as a result of treatment applications. The carbon content increased in all the treatments apart from the control. The highest amount of carbon was recorded in the combination of maize stover and compost under incorporated application treatment (MCI), which had an increase of 1.4% which was equivalent to 0.39 Mg C/ha (Appendix 2). It was followed by a combination of maize stover and compost under surface application (MCS) which increased by 1.37 %, an equivalent of 0.38 Mg C/ha. At the end of season 2, 0.1 % had been lost from the soil in the control treatment which was an equivalent of 0.03 Mg C/ha.

Percent carbon accumulation in the soil at the depth of 20-40 cm was also measured at the end of both seasons. Results obtained from both seasons showed that the effects of the treatments on soil carbon percent at the depth of 20-40 cm were not significantly different ($P<0.05$) (table 5). Though not significantly different, the soil carbon content, however, was found to increase with application of organic residues in some of the treatments. At the end of season 1, four treatments (CI, MS, MCS and MCI) recorded an increase in organic carbon while, in treatments CTRL, CS, and MI the organic carbon did not change from the baseline.

Table 5: Changes in soil organic carbon content for two seasons (2011/2012 short rains and 2012 long rains) at the depth of 20-40 cm

Treatment	Season 1				Season 2			
	BSL (% C)	S1 (% C)	Change (% C)	t- test p value	BSL (% C)	S2 (% C)	Change (% C)	t- test p value
CTRL	0.37	0.37	0.00	0.184	0.37	0.30	-0.07	0.230
CS	0.37	0.37	0.00	1.000	0.37	0.37	0.00	1.000
CI	0.37	0.43	0.80	0.270	0.37	0.50	0.13	0.529
MS	0.37	0.43	0.80	0.423	0.37	0.47	0.10	0.225
MI	0.43	0.43	0.00	0.270	0.43	0.50	0.07	0.423
MCS	0.40	0.43	0.03	0.423	0.40	0.43	0.03	0.199
MCI	0.40	0.53	0.13	0.383	0.40	0.60	0.20	0.074
SED	**0.045**	**0.089**	**-**	**-**	**0.045**	**0.102**	**-**	**-**
LSD$_{(0.05)}$	**0.158**	**0.191**	**-**	**-**	**0.158**	**0.22**	**-**	**-**
pValue$_{(0.05)}$	**0.949**	**0.595**	**-**	**-**	**0.949**	**0.165**	**-**	**-**

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), S1- (end of season 1), S2- (end of season 2), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

At the end of season 2, most treatments had increased the total carbon from the baseline except for the control and compost under surface application. There was a decrease in percent carbon in the control of 0.07% while the compost under surface application (CS) treatment did not change. A combination of compost and maize stover under incorporated application (MCI) gave the highest percent change (0.2%), followed by compost under incorporated application (CI) and maize stover under surface application (MS) with (0.13%) carbon change. The combination of maize stover and compost under surface application (MCS) treatment had the lowest percent carbon change (0.03%).

These results showed that soil carbon accumulation increased with organic residue incorporation. This is a clear indication that application of organic residues led to increased carbon sequestration in the soil. These findings are in consistence with findings of other researchers who found that organic amendments increased soil organic carbon as compared to control (Kowaljow and Mazzarino, 2007; Ngo et al., 2012; Neal et al., 2013). Similarly, Chivenge et al., (2011) in a study conducted in Embu, Kenya also reported an increase in carbon storage in soil with application of organic residues. Neal et al., (2013) in a study conducted in Australia also reported increased carbon storage in the soil with addition of organic residues by 2.6 Mg C/ha.

With increased carbon sequestration in the soil, adverse effects of global warming caused by increased concentrations of carbon dioxide in the atmosphere can be minimized. According to Prentice (2001) and Lal (2004b), increasing carbon sequestration in soils is one option helping tomitigate increasing atmospheric CO_2concentrations and global climate change. Application of organic matter increases plant biomass and yields as a result of increased carbon uptake. With increased vegetation cover, more carbon dioxide is absorbed during photosynthesis resulting to increased yields and also removing carbon dioxide from the atmosphere (Steinbeiss et al., 2008). In terrestrial ecosystems plants are able to reduce atmospheric $CO_2$and bind it in biomass (Steinbeiss et al., 2008).

Carbon in soil is a major source of energy for micro- organisms living in the soil. The potential of agricultural land to mitigate greenhouse gases and sequester C may be an added benefit of maintaining soil fertility levels through the use of best management practices (Fortuna et al., 2003).The sequestration of atmospheric carbon dioxide into soil organic carbon (SOC) to mitigate greenhouse gas emissions may become an important farm management strategy in the future (Neal et al., 2013). According to Neal et al., (2013) there is limited data available on the potential of organics to sequester soil organic carbon under best practice management.

Treatments which had organic residues incorporated had higher concentrations of organic carbon accumulation compared to the treatments which had organic residues placed on the surface. This was so due to little or no loss of carbon in form of carbon dioxide during mineralization of the organic residues.

More carbon accumulation was recorded at the 0-20 cm depth which was significantly different $P<0.05$ across the treatments, with more carbon accumulation being recorded in the incorporated maize stover- compost combination treatment. These observations are in consistent with those of Neal et al., (2013) who observed that increase in soil organic carbon was limited to the surface 0-10 cm depth in a study conducted in Australia. At the depth of 20-40 cm, the application of organic residues did not have a significant effect on the soil carbon. This could be due to accumulation of the organic residues at the top soil layer, with little or no organic residue movement or accumulation beneath the top soil layer. The concentrations of carbon decreased with increase in depth.

This observation was in line with observations of Kramer and Gleixner, (2008) who reported more concentrations of carbon in the 0-20 cm layer than the 20-40 cm layer. Steinbeiss et al., (2008) reported changes in carbon distribution in the soil profile with application of litter and an increase of organic carbon in the 0-20 cm layer. Gleixner et al., (2005) also observed increase in the carbon concentrations in the main rooting zone and a decrease in carbon concentrations beneath this zone.This decrease of C storage with depth could be as a result of incorporation of organic residues being done at the surface or near the surface.Similar observation was also reported by Steinbeiss et al., (2008) in Germany who reported an increase in soil organic carbon in the 0-20 cm layer and a decrease in the 20-40 cm layer.

4.1.2 Carbon sequestered in maize plants

Application of organic residues significantly increased the amount of carbon sequestered in the maize plants at $P = 0.05$ (Table 6). Maize stover and compost combined under incorporated application (MCI) stored the highest amounts of carbon in both the two seasons i.e. 2.47 Mg/ha in season 1 and 3.0 Mg/ha in season 2. The control treatment stored the lowest amounts of carbon in the maize plants tissues in both the two seasons i.e. 1.36 Mg/ha in season 1and 1.24 Mg/ha in season 2. This is attributed to increased nutrient availability for the plants and hence increased plant growth; as a result photosynthesis increased leading to increased C intake in the plants. With increased biomass plants were able to bind more C in them. According to Steinbeiss et al., (2008),plants are able to reduce atmospheric $CO_2$and bind it in biomass.

Table 6:Carbon sequestered in the maize plants (Mg/ha) atharvest time of season one (February 2012) and harvest time of season two (July 2012)

Treatment	**Season**	
	Season 1 (Mg/ha)	Season 2 (Mg/ha)
CTRL	1.35c	1.24d
CS	1.44c	1.55cd
CI	1.49c	2.36b
MS	2.05b	1.65cd
MI	2.16b	2.74ab
MCS	2.30ab	1.79c
MCI	2.47a	3.00a
SED	**0.10**	**0.13**
LSD	**0.33**	**0.53**
P value	**<0.001**	**<0.001**

Means with different letter(s) along the same column are statistically different at P= 0.05

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), S1- (end of season 1), S2- (end of season 2), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

4.1.3 Relationship between grain yield and carbon sequestered in maize plants

The relationship between the carbon sequestered in the maize plants and the grain yields obtained in seasons one and two are shown in Figures 2 and 3 respectively. A highly significant and positive correlation between the carbon sequestered in the maize plants and grain yields was observed in both seasons one and season two. Grain yield showed a very high correlation of $r^2 = 0.9908$ with sequestered carbon in season one while in season two that of grain yield with sequestered carbon was $r^2 = 0.956$. With more carbon being sequestered in the maize plant tissues, higher yields are expected due to increased photosynthesis.

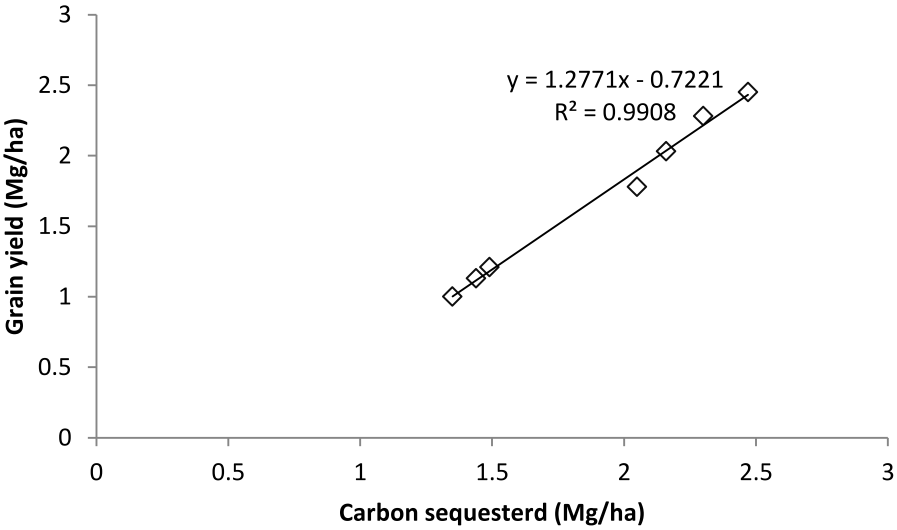

Figure 2: Relationship between grain yield and carbon sequestered in maize plants at harvest time in season one (February 2012)

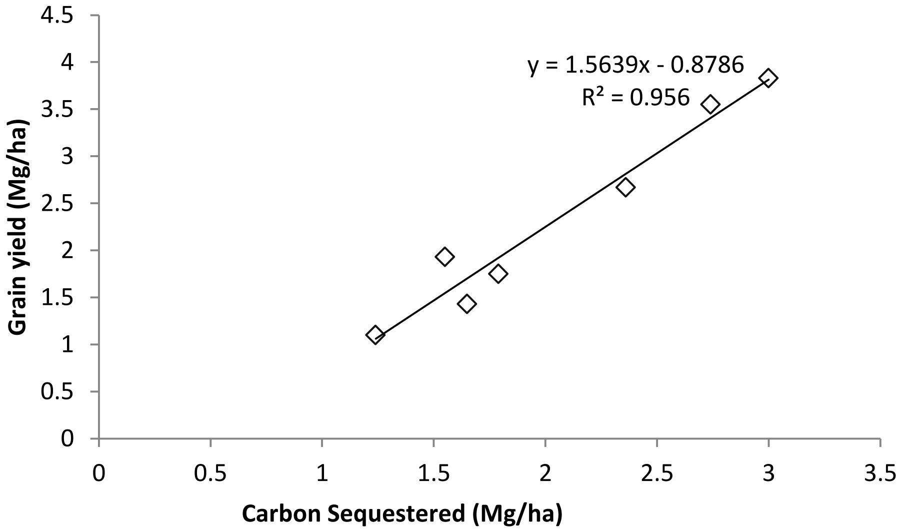

Figure 3: Relationship between grain yield and carbon sequestered in maize plants at harvest time in season two (July 2012)

4.2 Effect of organic residues on nutrient availability in soil

Generally, the application of the organic residues led to an increment in the concentrations of most nutrients in the soil. Similar observation was recorded by Mugweet al., (2007) in Meruwho reported changes in soil properties, with some parameters increasing and others were decreasing while working with organic materials (mucuna, calliandra, tithonia etc.). This is also in concurrence with Mbah and Nneji,

(2010) who reported an increase in organic matter, CEC, available phosphorus and exchangeable bases in the soil after incorporation of organic residues in Nigeria. Mutegi et al., 2012 in a study conducted in Meru South, Kenya reported an increase in general soil fertility parameters like total C, total N, Ca, Mg and K with application of organic residues.

Application of organic residues increased the concentrations of N, P, and K in the soil more than the control. This is a clear indication that application of organic residues, improve the fertility status of a soil. With increased nutrient availability in the soil, it is expected that plants will have plenty supply of nutrients and hence lead to increased yield productivity.

Treatments which had organic residues incorporated, had higher concentrations of N, P, K and CEC as compared to the treatments where the organic residues were surface applied. This could have been attributed to little or no loss of nutrients in the soil through erosion or through volatilization.

4.2.1 Effect of treatments on N

At seedling stage in season one, significant increase in total N (%) was recorded in soil with the application of organic residues at the depth 0-20 cm (Table 7). The highest percent increase in total N was recorded in the MCI treatment which increased by 0.06%. This was followed by CI and MI (0.04%), CS and MCS (0.03%) and MS (0.01%), while there was no change in the control treatment. At the depth 20-40 cm, no significant changes in the total nitrogen were recorded.

Table 7: Changes in total nitrogen content (%N) in the soil from the baseline at seedling stage (six weeks after planting) in season one (November, 2011)

Treatment	**0-20 cm**				**20-40 cm**			
	BSL	SS1	Change from baseline	t-test p value	BSL	SS1	Change from baseline	t-test p value
CTRL	0.09	0.09d	0.00	0.50	0.04	0.04	0.00	0.50
CS	0.11	0.14ab	0.03	0.07	0.04	0.05	0.01	0.13
CI	0.10	0.14ab	0.04	0.02*	0.05	0.05	0.00	0.50
MS	0.10	0.12c	0.01	0.27	0.05	0.05	0.00	0.50
MI	0.09	0.13bc	0.04	0.02*	0.05	0.05	0.00	0.50
MCS	0.10	0.13bc	0.03	0.07	0.04	0.05	0.01	0.28
MCI	0.10	0.15a	0.06	0.008*	0.05	0.06	0.01	0.19
SED	**0.016**	**0.009**	**-**	**-**	**0.009**	**0.009**	**-**	**-**
LSD$_{(0.05)}$	**0.034**	**0.02**	**-**	**-**	**0.019**	**0.02**	**-**	**-**
pValue$_{(0.05)}$	**0.858**	**<0.001**	**-**	**-**	**0.854**	**0.883**	**-**	**-**

Means with different letter(s) along the same column are statistically different at P= 0.05

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), SS1- (seedling stage of season 1), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

In season two, the application of organic residues significantly increased the total N (*P*<0.05) in all the treatments at the seedling stage, except in the control where the total N remained constant at the depth 0-20 cm (Table 8). A significant change of the total N from the baseline was also recorded in the treatments CI, MI, MCS and MCI at the depth

0-20 cm. At the depth 20-40 cm slight increase in the total N was recorded in treatments CS, MCS, and MCI only.

Table 8: Changes in total nitrogen content (%N) in the soil from the baseline at seedling stage (six weeks after planting) in season two (April, 2012)

Treatment	**0-20 cm**				**20-40 cm**			
	BSL	SS2	Change from baseline	t-test p value	BSL	SS2	Change from baseline	t-test p value
CTRL	0.09	0.09c	0.00	0.12	0.04	0.04	0.00	0.50
CS	0.11	0.14b	0.03	0.05	0.04	0.05	0.01	0.13
CI	0.10	0.14b	0.04	0.01*	0.05	0.05	0.00	0.50
MS	0.10	0.13b	0.03	0.06	0.05	0.05	0.00	0.50
MI	0.09	0.13b	0.04	0.02*	0.05	0.05	0.00	0.50
MCS	0.10	0.14b	0.04	0.04*	0.04	0.05	0.01	0.28
MCI	0.10	0.16a	0.06	0.002*	0.05	0.06	0.01	0.19
SED	**0.016**	**0.008**	**-**	**-**	**0.009**	**0.008**	**-**	**-**
LSD$_{(0.05)}$	**0.034**	**0.02**	**-**	**-**	**0.019**	**0.02**	**-**	**-**
pValue$_{(0.05)}$	**0.858**	**<0.001**	**-**	**-**	**0.854**	**0.798**	**-**	**-**

Means with different letter(s) along the same column are statistically different at P= 0.05

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), SS2- (seedling stage of season 2), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

The increase in N content in soil is due to the release of the mineral nitrogen in the organic residues as a result of mineralization. This was in tandem with the findings of Adjei-Nsiah, (2012) in Ghana who reported that incorporation of organic residues into the soil helps in accumulation of substantial amount of nitrogen into the soil system. Increase in N in the soil due to application of organic residues was also reported by Mbah and Nneji (2010) in Nigeria. Mutegi et al., (2012) also reported an increase in N as a result of organic residue incorporation in a study conducted in Meru south, Kenya.

4.2.2 Effect of treatments on available P in soil

At the depth 0-20 cm during seedling stage in season one (six weeks after planting), significant increase $P<0.05$ in concentrations of available P was recorded as a result of application of organic residues (Table 9). The highest increase in P was recorded in the MCI treatment which increased by 25% while the lowest increase was recorded in the control increasing by 5.58%. Significant changes in P from the baseline were recorded in treatments CI, MCS, and MCI in the depth 0-20 cm. At the depth 20-40 cm, there was no significant increase in P ($P<0.05$) and no significant changes with P from the baseline were observed at the depth 20-40 cm in all the treatments.

Table 9: Changes in available P (ppm) in the soil from the baseline at seedling stage (six weeks after planting) in season one (November, 2011)

Treatment	**0-20 cm**				**20-40 cm**			
	BSL	SS1	Change from baseline	t-test p value	BSL	SS1	Change from baseline	t-test p value
CTRL	11.00	11.67c	0.67	0.187	6.33	5.67	-0.66	0.115
CS	10.33	12.33c	2.00	0.051	5.33	6.00	0.67	0.281
CI	11.67	13.67b	2.00	0.006*	6.33	7.00	0.67	0.187
MS	10.00	11.33c	1.33	0.102	6.67	7.33	0.66	0.259
MI	12.00	13.33b	1.33	0.058	5.67	7.00	1.33	0.058
MCS	11.67	13.67b	2.00	0.028*	4.67	5.33	0.66	0.259
MCI	12.00	15.00a	3.00	0.011*	6.33	7.67	1.34	0.281
SED	**0.87**	**0.62**	**-**	**-**	**0.84**	**0.84**	**-**	**-**
LSD$_{(0.05)}$	**1.87**	**1.32**	**-**	**-**	**1.79**	**1.79**	**-**	**-**
pValue$_{(0.05)}$	**0.188**	**<0.001**	**-**	**-**	**0.263**	**0.093**	**-**	**-**

Means with different letter(s) along the same column are statistically different at P= 0.05

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), SS1- (seedling stage of season 1), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

At seedling stage in season two (six weeks after planting) at the depth 0-20 cm, significant increases (P<0.05) in concentrations of available P were recorded as a result of application of organic residues (Table 10). The highest concentration of P was recorded in the MCI treatment (15.67 ppm) while the lowest concentration was recorded in the control (CTRL) (12.00 ppm). Significant changes in P from the baseline were recorded in the following treatments (CS, CI, MS, MI, MCS and MCI). At the depth 20-40 cm, there were no significant increases in P (*P*<0.05) recorded. This may be explained by little or no leaching of nutrients. The changes in P from the baseline were also not significant at the depth 20-40 cm in all the treatments.

Table 10: Changes in available P (ppm) in the soil from the baseline at seedling stage (six weeks after planting) of season two (April, 2012)

Treatment	**0-20 cm**				**20-40 cm**			
	BSL	SS2	Change from baseline	t-test p value	BSL	SS2	Change from baseline	t-test p value
CTRL	11.00	12.00c	1.00	0.144	6.33	6.57	0.22	0.259
CS	10.33	12.67c	2.34	0.034*	5.33	6.00	0.67	0.174
CI	11.67	13.67bc	2.00	0.021*	6.33	6.00	-0.33	0.187
MS	10.00	12.67c	2.67	0.008*	6.67	7.33	0.66	0.259
MI	12.00	13.67bc	1.67	0.033*	5.67	6.00	0.33	0.115
MCS	11.67	14.33b	2.66	0.011*	4.67	5.33	0.66	0.259
MCI	12.00	15.67a	3.67	0.002*	6.33	6.67	0.34	0.115
SED	**0.87**	**0.62**	**-**	**-**	**0.84**	**0.85**	**-**	**-**
LSD$_{(0.05)}$	**1.87**	**1.32**	**-**	**-**	**1.79**	**1.89**	**-**	**-**
pValue$_{(0.05)}$	**0.188**	**<0.001**	**-**	**-**	**0.263**	**0.088**	**-**	**-**

Means with different letter(s) along the same column are statistically different at P= 0.05

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), SS2- (seedling stage of season 2), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

Available P in the soil significantly increased with the application of the organic residues. These findings agree with those of Tognetti et al., (2008) who reported an increase in available P in the soil with the application of compost in a study conducted in Argentina. Similar findings were also reported by Guo and Sims, (2002) in a study conducted in New Zealand which reported an increase in P by more than 60% with litter application.

4.2.3 Effect of treatments on K^+ in soil

Significant increase in the K concentrations in the soil during seedling stage (six weeks after planting) in season one was recorded as a result of organic residue application $P<0.05$ at the depth 0-20cm (Table 11). There was a significant change from the baseline with application of compost under surface application and also under incorporated application. A significant change from the baseline was recorded in the following treatments MI, MCS and MCI. However, at the depth 20-40 cm, changes in K from the baseline were not significant at $P=0.05$.

Table 11: Changes in K concentration (cmol+/kg) in the soil from the baseline at seedling stage (six weeks after planting) in season one (November, 2011)

Treatment	**0-20 cm**				**20-40 cm**			
	BSL	SS1	Change from baseline	t-test p value	BSL	SS1	Change from baseline	t-test p value
CTRL	1.02	1.03b	0.01	0.144	0.59	0.57	-0.02	0.281
CS	1.02	1.06a	0.04	0.019*	0.57	0.58	0.01	0.259
CI	1.02	1.06a	0.04	0.003*	0.58	0.58	0.00	0.383
MS	1.03	1.04b	0.01	0.115	0.57	0.58	0.01	0.281
MI	1.02	1.06a	0.04	0.019*	0.58	0.58	0.00	0.500
MCS	1.03	1.06a	0.03	0.014*	0.58	0.59	0.01	0.281
MCI	1.02	1.07a	0.05	0.006*	0.59	0.59	0.00	0.500
SED	**0.02**	**0.008**	**-**	**-**	**0.01**	**0.08**	**-**	**-**
LSD$_{(0.05)}$	**0.02**	**0.02**	**-**	**-**	**0.02**	**0.02**	**-**	**-**
pValue$_{(0.05)}$	**0.942**	**<0.001**	**-**	**-**	**0.507**	**0.569**	**-**	**-**

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), SS1- (seedling stage of season 1), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

Significant increase in the K concentrations in the soil was recorded as a result of organic residue application during seedling stage (six weeks after planting) in season two

$P<0.001$ (Table 12). Treatment MCI had the highest concentration (1.08 cmol+/kg) followed by treatments MCS and CI (1.07 cmol+/kg). This was followed by CS (1.06 cmol+/kg) > MI (1.05 cmol+/kg) > MS (1.04 cmol+/kg). At the depth 0-20cm, there was a significant change in K concentration ($P=0.05$) from the baseline with application of organic residues in all the treatments except in the control and maize stover under surface application. At the depth 20-40 cm, changes in K from the baseline were not significant in all the treatments.

Table 12: Changes in K concentration (cmol+/kg) in the soil from the baseline at seedling stage (six weeks after planting) in season two (April, 2012)

Treatment	0-20 cm				20-40 cm			
	BSL	SS2	Change from baseline	t-test p value	BSL	SS2	Change from baseline	t-test p value
CTRL	1.02	1.04b	0.02	0.078	0.59	0.58	-0.01	0.321
CS	1.02	1.06a	0.04	0.0197*	0.57	0.58	0.01	0.259
CI	1.02	1.07a	0.05	0.001*	0.58	0.59	0.01	0.174
MS	1.03	1.04b	0.01	0.051	0.57	0.58	0.01	0.281
MI	1.02	1.05b	0.03	0.031*	0.58	0.58	0.00	0.500
MCS	1.03	1.07a	0.04	0.003*	0.58	0.59	0.01	0.174
MCI	1.02	1.08a	0.06	0.001*	0.59	0.59	0.00	0.362
SED	**0.02**	**0.01**	**-**	**-**	**0.01**	**0.009**	**-**	**-**
LSD$_{(0.05)}$	**0.02**	**0.02**	**-**	**-**	**0.02**	**0.02**	**-**	**-**
pValue$_{(0.05)}$	**0.942**	**0.011**	**-**	**-**	**0.507**	**0.433**	**-**	**-**

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), SS2- (seedling stage of season 2), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

K concentrations in the soil increased with the application of organic residues. Similar finding was also reported by Ebid et al., (2007) who reported a significant increase in K and other nutrients in the soil with application of maize residues and compost in Egypt. Kaur and Benipal (2006) also reported increased concentration of K in the soil with application of farm yard manure. Paradelo et al., (2012) reported an increase in the concentration of K in the soil under an incubation study carried out in Spain. According to Paradelo et al., (2012) application of compost increased K concentration in the soil from 150-200 mg/Kg which was a 50% increase.

4.2.4 Effect of treatments on CEC

At seedling stage (six weeks after planting) in season one application of organic residues increased the cation exchange capacity of the soil significantly ($p<0.05$) at both depths (Table 13). Application of maize stover and compost under incorporated application (MCI) gave the highest cation exchange capacity (5.05 cmol/kg of soil) at the depth of 0-20 cm and 3.73 cmol/kg at the depth of 20-40 cm respectively. The control had the lowest CEC at both depths 0-20 cm and 20-40 cm i.e. 2.95 cmol/kg and 2.39 cmol/kg of soil respectively. At the depth 0-20 cm, the change in CEC from the baseline was significant in all the treatments except in the control treatment. At the depth 20-40 cm the change in CEC from the baseline was significant in all the treatments except in the control and a combination of maize stover and compost under surface (MCS) application.

Table 13: Changes in Cation Exchange Capacity (cmol/kg) in the soil from the baseline at seedling stage (six weeks after planting) in season one (November, 2011)

Treatment	**0-20 cm**				**20-40 cm**			
	BSL	SS1	Change from baseline	t-test p value	BSL	SS1	Change from baseline	t-test p value
CTRL	3.06	2.95e	-0.11	0.156	2.40	2.39d	-0.01	0.893
CS	2.99	3.87d	0.88	<0.001*	2.46	2.90c	0.44	0.021*
CI	3.02	4.00cd	0.98	0.004*	2.45	3.15bc	0.70	0.007*
MS	3.04	4.03c	0.99	0.004*	2.43	3.09bc	0.66	0.009*
MI	3.13	4.37b	1.24	0.005*	2.46	3.36b	0.9	0.026*
MCS	2.97	4.25b	1.28	<0.001*	2.37	3.00c	0.63	0.094
MCI	3.04	5.05a	2.21	0.003*	2.51	3.73a	1.22	0.002*
SED	**0.07**	**0.065**	**-**	**-**	**0.06**	**0.153**	**-**	**-**
$LSD_{(0.05)}$	**0.15**	**0.134**	**-**	**-**	**0.12**	**0.33**	**-**	**-**
$pValue_{(0.05)}$	**0.406**	**<0.001**	**-**	**-**	**0.294**	**<0.001**	**-**	**-**

Means with different letter(s) along the same column are statistically different at P= 0.05

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), SS1- (seedling stage of season 1), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

Application of organic residues increased the cation exchange capacity of the soil significantly (*P*<0.05) at both depths of 0-20 cm and 20-40 cm in season two. Application of maize stover and compost under incorporated application (MCI) gave the highest increase in cation exchange capacity of 70% at the depth of 0-20 cm and 53.78%

at the depth of 20-40 cm respectively. The control recorded a decrease in CEC at both depths (0-20 cm and 20-40 cm).

At the depth 0-20 cm, the change in CEC from the baseline was significant in all the treatments except in the control treatment while, at the depth 20-40 cm the changes in CEC from the baseline were significant in all the treatments except in the control and a combination of maize stover and compost under surface (MCS) treatment.

Table 14: Changes in Cation Exchange Capacity (cmol/kg) in the soil from the baseline at seedling stage (six weeks after planting) in season two (April, 2012)

Treatment	**0-20 cm**				**20-40 cm**			
	BSL	SS2	Change from baseline	t-test p value	BSL	SS2	Change from baseline	t-test p value
CTRL	3.06	3.00f	-0.06	0.331	2.40	2.39e	-0.01	0.966
CS	2.99	4.02e	1.03	<0.001*	2.46	2.83d	0.37	0.007*
CI	3.02	4.24c	1.22	0.009*	2.45	3.15cd	0.70	0.002*
MS	3.04	4.15d	1.11	0.005*	2.43	3.26bc	0.83	0.009*
MI	3.13	4.56b	1.43	<0.001*	2.46	3.57ab	1.11	0.036*
MCS	2.97	4.61b	1.64	<0.001*	2.37	3.06cd	0.69	0.060
MCI	3.04	5.17a	2.13	0.002*	2.51	3.86a	1.35	0.002*
SED	**0.07**	**0.08**	**-**	**-**	**0.06**	**0.35**	**-**	**-**
LSD$_{(0.05)}$	**0.15**	**0.16**	**-**	**-**	**0.12**	**0.35**	**-**	**-**
pValue$_{(0.05)}$	**0.406**	**<0.001**	**-**	**-**	**0.294**	**<0.001**	**-**	**-**

Means with different letter(s) along the same column are statistically different at P= 0.05

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated), BSL- (baseline), SS2- (seedling stage of season 2), SED- (Standard Error of Differences between means), LSD- (Least Significance Difference).

Application of organic residues increased the cation exchange capacity of the soil. Improved cation exchange capacity is important since it leads to increased availability of plant nutrients and hence improves the fertility status of the soil. Similar observation was made by Conant et al., (2002) and Franzluebbers (2010) who reported that application of organic residues increased cation exchange capacity due to increased soil organic carbon pools. Abdel-Rahman, (2009) in a study conducted in Sahel North Burkina Faso also reported an increase in cation exchange capacity from 4-6 cmol kg^{-1} due to compost application.

4.3 Effect of treatments on maize growth and yields

4.3.1 Treatment effects on maize plants heights

Plant height is an important parameter in determining the final plant yields. Results of maize plants heights during seedling stage (six weeks after planting) and at harvest time are presented in Table 15. During seedling stage, a combination of maize stover and compost under incorporated application method (MCI) gave the tallest plants in both seasons. The control had the shortest plants throughout the two seasons.

Table 15: Plant heights in cm, six weeks after planting (6 WAP) and at harvest of both season 1 and 2.

Treatment	**Season 1**		**Season 2**	
	6 WAP	Harvest	6 WAP	Harvest
CTRL	72.9	188.67e	77	192.78d
CS	80.1	227d	81.8	240c
CI	80.7	236.44c	88.8	241.78c
MS	80.0	235.33c	85.6	236c
MI	81.8	251.78b	85.0	268.89b
MCS	81.4	256.67b	85.1	269.11b
MCI	84.7	269.56a	93.7	286.33a
SED	**4.71**	**3.054**	**5.03**	**2.531**
$LSD_{(0.05)}$	**9.43**	**6.12**	**10.08**	**5.07**
P $Value_{(0.05)}$	**0.336**	**<0.001**	**0.061**	**<0.001**

Means with different letter(s) along the same column are statistically different at P= 0.05

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated).

At harvest time maize plants heights in relation to treatments were significantly different *P*<0.05 (Table 15). Combination of maize stover and compost under incorporated application method (MCI) gave the tallest plants in the two seasons, that is 269.6 cm and 286.3 cm, for season 1 and 2 respectively. This was followed closely by a combination of maize stover and compost under surface application (MCS) and maize stover under incorporated application (MI). The control (CTRL) had the shortest maize

plants. Maize plant height affected the final maize yields (both grain yield and total dry matter) across the two seasons. Maize plants during harvesting in the 2012 long rains were slightly taller than those of 2011/2012 short season. A similar pattern was observed with maize yields in the two seasons with the 2012 long rains season having slightly higher yields than the 2011/2012 short rains season. These findings are in agreement with the findings of Mucheru (2003) in Meru who found that maize yields were greatly affected by maize plant heights.

4.3.2 Effect of treatments on maize yields

Results showed that maize yields responded to applied treatments and that the response was dependent on the organic residue source (Table 16). In season one, results showed that both grain yield and total dry matter (DM) yield were significantly different at $P<0.05$. Treatment MCI gave the highest grain yield (2.45 Mg/ha) and also the highest total dry matter yield (5.48 Mg/ha) respectively. This was more than two times higher than the control treatment, which yielded (1.0 Mg/ha) grain yield and (3.02 Mg/ha) total dry matter. In general, treatments with organic residues incorporated had higher yields than other treatments. This was due to better synchrony of nutrient availability to maize crop demand and also moisture retention. Sole application of maize stover gave significantly higher grain yield (1.91 Mg/ha) and total dry matter (4.7 Mg/ha) than sole compost application which gave (1.18) Mg/ha grain yield and (3.3) Mg/ha total dry matter. It was also found that the control gave significantly lower grain and total dry matter yields compared to all the other treatments.

Results obtained during the second season showedsignificant differences among the treatments on maize grain yield and total dry matter yield ($P<0.05$) (Table 16). Similarly, treatment MCI gave the highest grain yield (3.83 Mg/ha) and total dry matter yield (6.67 Mg/ha) as was the case in season one. Maize stover under incorporated application (MI) followed slightly, producing 3.55 Mg/ha grain yield and 6.08 Mg/ha total dry matter. Although there was significantly higher maize grain yield and total dry matter yield recorded in treatments that had compost and maize stover applied either sole or combined under incorporated application, grain and total dry matter yields obtained from application of compost and maize stover under surface application (MCS) did not differ significantly from each other and were slightly lower than yield obtained from incorporated treatments. This was also true with sole application of both compost and maize stover under surface application which gave lower yields compared to sole application of compost and maize stover under incorporated application.

Table 16: Effect of treatments on maize grain yields and total dry matter yields of both seasons 1 and 2

Treatment	**Grain yield (Mg/ha)**		**Total dry matter (Mg/ha)**	
	Season 1	Season 2	Season 1	Season 2
CTRL	1.0b	1.10c	3.02b	2.75c
CS	1.13b	1.93bc	3.2b	3.45bc
CI	1.21b	2.67ab	3.3b	5.25ab
MS	1.78b	1.43c	4.55a	3.67c
MI	2.03a	3.55ab	4.80a	6.08ab
MCS	2.28a	1.75bc	5.12a	3.97bc
MCI	2.45a	3.83a	5.48a	6.67a
SED	**0.22**	**0.45**	**0.44**	**0.75**
LSD$_{(0.05)}$	**0.47**	**0.96**	**0.95**	**1.61**
P Value$_{(0.05)}$	**<0.001**	**<0.001**	**<0.001**	**<0.001**

Means with different letter(s) along the same column are statistically different at P= 0.05

CTRL- Control, CS- compost (surface), CI- compost (incorporated), MS- maize stover (surface), MI- maize stover (incorporated), MCS- maize stover and compost (surface), MCI- maize stover and compost (incorporated).

Application of organic residues increased the maize yields in terms of grain and total biomass yield. Similar results were reported by Nyongesa et al., (2009) in Nandi district, Kenya who observed that organic residues application increased grain yield and stover in maize. A combination of maize stover and compost (incorporated application) gave the highest maize yields in terms of grain and biomass yields as compared to the control which gave the lowest maize yields. This can be attributed to nutrient release from both the maize stover and compost, and also more nutrients having been incorporated. Since incorporation was done two weeks before planting giving time for mineralization to take place, this could have led to a better synchrony of nutrient availability to maize crop demand. Maize stover could also have acted as mulch which assisted in water conservation and hence moisture availability to the plants for a longer growing period leading to increased yields. Similar findings were reported by other researchers like Maskena et al., (1993) who observed that soil incorporation of organic residues improves soil water relation for plant and microbial activity, thus enhancing nutrient cycling hence improved yields. Power et al., (1998) showed that covering the soil surface with layers of residue increased infiltration and prevented formation of compaction caused by raindrop impact on bare soils. Mbah(2009) observed that, there was improved soil condition and temperature in mulched plots relative to non-mulched plots leading to improved yields.

Incorporated application of all the organic residues gave higher yields than surface application; this could be attributed to improved nutrient synchronization. These findings agree with those of Mutegi et al., (2012) in a study conducted in Meru south, Kenya who reported increased maize yields with organic residues incorporation. Similar results were also reported by Muhammad et al., (2011) in Pakistan who reported higher maize yield component with residue incorporation compared to surface application.

Generally the findings of this study suggest that application of organic resources is very beneficial in terms of maize yield improvement. These findings corroborate those ofNziguheba et al., (2000) in western Kenya, working with (calliandra, senna, tithonia and lantana) who reported that organic residues can increase maize yields more than or similar to application of inorganic fertilizers which have been widely used for a long time all over the world (Ngo et al., 2012).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Application of organic residues resulted in organic C accumulation in soil at the 0-20 cm soil depth. A combination of 5 ton/ha maize stover and 10 ton/ha compost under incorporated application stored the highest total soil carbon in both seasons, that is 0.36Mg C/hain season one and 0.39 Mg C/ha in season two.

The study also found that there was a substantial accumulation of nutrients into the soil with the application of organic residues. Application of organic residue increased the availability of total N, P and K at the depth of 0-20 cm in both seasons. Application of organic residues also increased the cation exchange capacity of the soil in both seasons. This enhanced growth of maize crops and hence increased maize yields were recorded. A combination of 5 ton/ha maize stover and 10 ton/ha compost under incorporated application gave the highest concentrations of the nutrients in soil and also the highest cation exchange capacity.

Application of organic residues increased the growth of the maize crops and also increased the maize yields. A combination of 5 ton/ha maize stover and 10 ton/ha compost under incorporated application recorded the highest maize grain yields and also total biomass dry matter in both the two cropping seasons.

Results of the present study have demonstrated that application of organic residues in the soil has a profound influence on soil carbon storage, nutrient availability in the soil and maize yields. Treatment with 5 ton/ha maize stover and 10 ton/ha compost under incorporated application was more effective in increasing soil carbon storage, nutrient concentrations in soil for plant use and consequently in increasing maize yields.

5.2 Recommendations

Based on the findings of this study the following recommendations have been derived;

- Farmers in the study area and other similar areas in Kenya should not only be encouraged to combine 10 ton/ha compost and 5 ton/ha maize stover in their farms in order to improve soil productivity and consequently yields but also to incorporate them in soil to increase maize yields.
- Besides increased maize yields and improved soil fertility, soil carbon storage will be improved and this will have a great impact on environmental conservation.
- Since the current study was carried out for two seasons, further research needs to be done to determine the right period it will take to establish an equilibrium and the upper limit for soil carbon storage using these organic residues.
- Further research to explore the possibilities of storing carbon and increasing productivity using other organic residues apart from the ones used in this study.

REFERENCES:

Abdel-Rahma G. (2009). Impact of compost on soil properties and crop productivity in the Sahel north Burkina Faso.*American- Eurasian J. Agric. And Environ. Sci.,*6: 220- 226

Adjei-Nsiah S. (2012). Evaluating sustainable cropping sequences with cassava and three grain legume crops: Effects on soil fertility and maize yields in the semi-deciduous forest zone of Ghana.*Journal of Soil Science and Environmental Management*, 3: 49-55

Bationo A. and Buerkert A. (2001).Soil organic carbon management for sustainable land use in sudano- sahelian West Africa.*Nutrient cycling in Agro ecosystems*, 61: 131-142

Bationo A., Kihara J., Vanlauwe B., Waswa B., and Kimetu J. (2007).Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural systems Journal,* 94: 13-25

Bresson L.M., Koch C., Le Bissonnais Y., Barriuso E. and Lecomte V. (2001).Soil surface structure stabilization by municipal waste compost application.*Soil Science Society of America Journal*, 65: 1804-1811.

Bolland M.D., Allen D.G. and Walton K.S. (2003). Soil testing for phosphorus: comparing the Mehlich 3 and Colwell procedures for soils of south-western Australia. *Australian Journal of Soil Research,* 41: 1185-1200

Cantanazaro C.J., Williams K.A., and Sauve R.J. (1998). Slow release versus water soluble fertilization affects nutrient leaching and growth of potted chrysanthemum. *Journal of Plant Nutrition,* 21: 1025-1036.

Caravaca F., Hernandez T., Garcia C., and Roldan A. (2002). Improvement of rhizosphereaggregate stability of afforested semiarid plant species subjected to mycorrhizal inoculation and compost addition. *Geoderma,* 108: 133-144.

Celik I., Ortas I. and Kilic S. (2004).Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil.*Soil and Tillage Research*, 78: 59-67.

Chapman, H.D. (1965). Cation exchange capacity.In Methods of Soil Analysis. Black, C. A.(ed.). Part 2, pp. 891-901. Number 9. Series Agronomy: Am. Inst. Agronomy, Madison, Wisconsin

Chivenge P., Vanlauwe B., Gentile R., Wangechi H., Mugendi D., Van Kessel C., and Six J. (2011). Organic and Mineral input management to enhance crop productivity in central Kenya.*Agronomy Journal*, 101: 1266-1275

Colman B., Fierer N., and Schimel J. (2008).Abiotic nitrate incorporation and the ferrous wheel.*Biogeochemistry,* 91: 223-227

Conant R.T., Paustian K., and Elliott E.T. (2002). Pastureland Use in the Southeastern US: Implications for Carbon Sequestration,pp. 423-432

Craswell E.T and Lefroy R.D.B. (2001).The role and function of organic matter in tropical soils.*Nutrient Cycling in Agroecosystems,* 61: 7-18

Danga B.O., Ouma, J.P., Wakindiki, I.I. C., and Asher Bar-Tal. 2009. Legume–Wheat Rotation Effects on Residual Soil Moisture, Nitrogen and Wheat Yield in Tropical Regions. *Advances in Agronomy*, Vol 101.pp.315-349

Davidson E.A., Dail D., and Chorover J. (2008). Iron interference in the quantification of nitrate in soil extracts and its effect on hypothesized abiotic immobilization of nitrate. *Biogeochemistry,* 90: 65-73

Ebid A., Ueno H., Ghoneim A. and Asagi N. (2007).Effect of maize residue compost application on growth, yield of some vegetables and soil properties. Bull. Exp. Farm Fac. Agri., Ehime Univ. 29: 1-9

Edward J. A., Paul R.P., and Coleman K. (2009). Soil Organic Matter: Its Importance in Sustainable Agriculture and Carbon Dioxide Fluxes. *Advances in Agronomy,* 101: pp. 1-57

Fortuna A., Harwood R., Kizilkaya K. and Paul E.A. (2003).Optimizing nutrient availability and potential carbon sequestrationin an agroecosystem.*Soil Biology & Biochemistry,* 35: 1005-1013

Franzluebbers A.J. (2010). Soil organic carbon in managed pastures of the southeastern United States of America. In: Abberton M.T., Conant R., Batello C. (Eds.), Grassland Carbon Sequestration: Management, Policy and Economics. FAO, Rome, pp. 163-175

Frossard E., Skrabal P., Sinaj S., BangerterF. andTraoré O. (2002). Forms and exchangeability of inorganic phosphate in composted solid organic wastes. *Nutrient cycling in Agroecosystems*, 62: 103–113.

Gardenas A.I., Agren G.I., Bird J.A., Clarholm M., Hallin S., Ineson P., Katterer T., Knicker H., Nilsson S.I., Nasholm T., Ogle S., Paustian K., Persson T., and Stendahl J. (2011). Knowledge gaps in soil carbon and nitrogen interactions- From molecular to global scale. *Soil Biology and Biochemistry*, 43: 702-717

Giller K.E. and Cadisch G. (1995).Future benefits from biological nitrogen fixation: an ecological approach to agriculture. *Plant and Soil Journal*, 174: 255-277.

Gleixner G., Kramer C., Hahn V. and Sachse D. (2005).The effect of biodiversity on carbon storage in soils.*Ecol. Stud.,* 176: 165-183

Guo L.B. and Sims R.E.H. (2002). Eucalypt litter decomposition and nutrient release under a short rotation forest regime and effluent irrigation treatments in New Zealand: II. Internal effects.*Soil Biology & Biochemistry*, 34: 913-922

Hargreaves J.C, Adl M. S and Warman P. R (2008).A review of the use of composted municipal solid waste inagriculture.*Agriculture, Ecosystems and the Environment*, 123: 1-14

He Z, X Yang, B A Kahn, P J Stoffella, D V Calvert 2005.Ventajasquesuponen la utilización de compost para la nutriciónfosfórica, potásica, cálcica, magnésica y de micronutrientes. In: *Utilización de compost en lossistemas de cultivo hortícola*. P J Stoffella, B A Kahn (eds.). Mundi-Prensa, Madrid, Spain, pp. 307-319

Hepperly P., Lotter D., Ulsh C.Z., Seidel R. and Reider C. (2009). Compost, manure and synthetic fertilizer influences crop yields, soil properties, nitrate leaching and crop nutrient content. *Compost Science & Utilization*, 17: 117-126

Intergovernmental Panel on Climate Change (IPCC), (2007).Fourth Assessment Report.

Kaur N. and Benipal D.S. (2006).Effect of crop residue and farmyard manure on K forms on soils of long term fertility experiment.*Indian J. Crop Science*. 1, 161-164

Keeney D.R. and Nelson D.W. (1982).Nitrogen- inorganic forms. In: Page A.L., Miller P.H., and Keeney D.R. (eds), Methods of Soil Analysis. Agronomy 9, 2nded. American Society of Agronomy, Madison, Winscon, USA, pp. 648- 698

Kirschbaum M.U.F. (2000). Will changes in soil organic carbon act as a positive or negative feedback on global warming? *Biogeochemistry,* 48: 21–51

Kleber M., Sollins P., and Sutton R. (2007). A conceptual model of organo-mineral interactions in soils: Self-assembly of organic molecular fragments into zonal structures on mineral surfaces. *Biogeochemistry*, 85: 9-24

Knicker H. (2004). Stabilization of N compounds in soil and organic matter rich sediments- what is the difference? *Marine Chemistry*, 92: 167-195

Knicker H. (2011). SoilorganicN – Anunder-rated player forC sequestration insoils? *Soil Biology and Biochemistry*, 43: 1118-1129

Kowaljow E. and Mazzarino M.J. (2007). Soil restoration in semiarid Patagonia: Chemical and biological response to different compost quality. *Soil Biology & Biochemistry*, 39, 1580-1588

Kramer C and Gleixner G. (2008). Soil organic matter in soil depth profiles: Distinct carbon preferences of microbial groups during carbon transformation. *Soil Biology and Biochemistry*, 40: 425-433

Krotz, L., Galotta, W. &Giazzi, G. (2000).Nitrogen Determination in Soils and Plants by FlashCombustion using Argon as Carrier Gas. Retrieved from http://apps.thermoscientific.com/media/cmd/hypersite-events/Pittcon-2014/posters/PN42209_PC2014.pdf

Laekemariam F and Gidago G. (2012).Response of Maize (Zea mays L.) to Integrated Fertilizer Application in Wolatia, South Ethiopia.*Advances in Life Science and Technology,* 5: 2224-7181

Lal R. (2004b). Soil carbon sequestration to mitigate climate change.Geoderma, 123, 1–22.

Lal R. (2009). Sequestering Atmospheric Carbon Dioxide.*Critical Reviews in Plant sciences,* 28: 90-96

Larchevêque M., Montès N., Baldy V. and Dupouyet S. (2005).Vegetation dynamics after compost amendment in a Mediterranean post-fire ecosystem. *AgricultureEcosystems and Environment,* 110: 241-248

Marschner, H., 2002. Mineral Nutrition of Higher Plants. Academic Press, San Diego. pp. 889

Martin D., Lal T., Sachdev C.B., Sharma J.P. (2010). Soil organic carbon storage changes with climatic change, Landform and land use conditions in Garhwals hills of the Indian Himalayan Mountains. *Agriculture, Ecosystems and Environment*, 138: 64-73

Maskena MA, Power JF, Doran JW, Wilhelm WW (1993). Residualeffects of Nitrogen uptake.*Soil Sci. Soc. Am. J*., 57: 155-156.

Mbah C.N. andNneji R.K. (2010). Effect of different crop residue management techniques on selected soil properties and grain production of maize. *African Journal of Agricultural Research.* 6(17): 4149-4152

Mbah C.N (2009). Physical properties of anultisol under plastic film and no- mulches and their effect on the yield of maize.*J. Am. Sci*., 5(5): 25-30.

Mehlich A. (1984). Mehlich-3 soil test extractant: a modification of Mehlich-2 extractant. *Communications in Soil science and Plant Analysis*, 15: 1409-1416

Mekuria W. (2012). The Potential Role of Soil-based Interventions in Increasing Maize Yield: A Case Study of Organic and Clay-based Soil Amendments in Central Laos. *International Water Management Institute (IWMI), Laos*

Mochoge B. and Danga B.O. (2010).Run-off rain water harvesting, application of manure and NP fertilizers on maize production in smallholder farms in semi-arid parts of Kenya. Final Report to NCST

Mucheru, M.W. (2003). Soil fertility technologies for increased food production in Chuka, Meru south district, Kenya. A maters thesis submitted to Kenyatta University

Mugwe, J.N. (2007). An evaluation of integrated soil fertility management practices in Meru South District, Kenya. A PhD thesis submitted to Kenyatta University

Mugwe J., Mugendi D., Kungu J., and Muna M. (2008). Maize yields response to application of organic and inorganic input under on-station and on-farm experiments in Central Kenya. *ExplAgric*, 45: 47- 59

Muhammad A., Mohammad T. J, Mohammad J. K, Muhammad S., Iqbal M., Ziauddin, Habib A., Shahenshah and Muhammad Z. H (2011).Effect of cropping system and residue management on maize.*Pak. J. Bot*, 43: 915-920

Mutegi E.M, Kung'u J.B, Muna M, Pieter P, Mugendi D.N. (2012). Complementary effects of organic and mineral fertilizers on maize production in the small holder farms of Meru south district, Kenya.*Agricultural Sciences,* 3(2): 221-229

Neal J.S., Eldridge S.M., Fulkerson W.J., Lawrie R. and Barchia I.M. (2013).Differences in soil carbon sequestration and soil nitrogen among forages usedby the dairy industry.*Soil Biology and Biochemistry*, 57: 542-548

Ngo P., Rumbel C., Doan T., and Jouquet P. (2012). The effect of earthworms on carbon storage and soil organic matter composition in tropical soil amended with compost and vermicompost. *Soil Biology & Biochemistry*, 50: 214-220

Nyamangara J., Bergstrom L.F, Piha M.I., and Giller K.E. (2003). Effect of combined cattle manure and mineral nitrogen on maize N uptake and grain yield. *African Crop Science Journal*, 11: 289-300

Nyongesa H.W., Obura R.K., Kitur B.K., Ouma J.P., and Nakhone L.N. (2009).Effect of organic and inorganic nutrient sources on maize yield and yield components in Nandi district, Rift valley province, Kenya.*African Crop Science conference proceedings*, 9: 55-61

Nziguheba G., Merckx R., Palm C.A. and Rao M.R. (2000). Organic residues affect phosphorus availability and maize yields in a Nitisol of western Kenya. *Biology fertility Soils*, 32: 328-339

Okalebo, J.R., Gathua, K.W. &Woomer P.L. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual *Second Edition*. TCBF-CIAT and SACRED Africa, Nairobi, Kenya.pp 22-78

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

Palm C.A., Gacheno 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 Journal*, 83: 27-42

Pan G., Smith P. and Pan W. (2009).The role of soil organic matter in maintaining the productivity and yield stability of cereals in China.*Agriculture, Ecosystems &Environment*, 129: 344–348

Paradelo R., Deveas-Rey R., Cancelo-Gonzalez J., Basanta R., Pena M.T., Diaz-Fierros F. and Barral M.T. (2012). Effect of a compost mulch on seed germination and plant growth in a burnt forest soil from NW Spain. *Journal of Soil Science and Plant Nutrition*, 1: 73-86

Post W.M., and Kwon K.C. (2000). Soil carbon sequestration and land-use change: processes and potential. *Global Change*, 6:317–327

Power J.F, Koerner O.T, Noran J.W, andWhilhelm W.W (1998). Residual effects of crop residues on grain production and selected properties.*Soil Sci. Am. J.*, 62: 1393-1397.

Prentice I.C. (2001).Interactions of climate change and the terrestrial biosphere. In: Bengtsson L.O., Hammer C.U. (Eds.), Geosphere–Biosphere Interactions and Climate. Cambridge University Press, Cambridge. 176–198

Rillig M.C., Caldwell B.A., Wosten H.A.B., and Sollins P. (2007). Role of proteins in soil carbon and nitrogen storage: controls on persistence. *Biogeochemistry*, 85: 25-44

Roose E. and Barthes B. (2001). Organic Matter Management for Soil conservation and Productivity restoration in Africa: a contribution from francophone research. *Nutrient cycling in Agro ecosystems journal*. 61: 159-170

Sakala W., Cadisch G., and Giller K.E. (2000).Interactions between residues of maize and pigeon pea and mineral N fertilizers during decomposition and N mineralization.*Soil Biology and Biochemistry*, 32: 679-688

Scherr S.J. (1999). Soil Degradation: A Threat to Developing- Country Food Security by 2020? Food, Agriculture, and the Environment Discussion Paper 27. International Food Policy Research Institute 2033 K Street, N.W. Washington, DC2006-1002 U.S.A

Shrestha B.M., Sitaula B.K., Singh B.R. and Bajracharya R.M. (2004). Fluxes of CO_2 and CH_4 in soil profiles of mountainous watershed of Nepal as influenced by land use, temperature, moisture and substrate addition. *Nutrient cycling in Agroecosystems*, 68: 155-164

Smaling E.M.A., Nandwa S.M., and Janssen B.H. (1997). Soil fertility is at stake. In replenishing soil fertility in Africa. Special publication No. 51Madison, Wisconsin: American Society of Agronomy and Soil Science Society of America

Smith P. (2004). Carbon sequestration in croplands: the potential in Europe and the global context. *European Journal*, 20: 229-236

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

Steinbeiss S., Temperton V.M. and Gleixner G. (2008).Mechanisms of short-term soil carbon in experimental grasslands.*Soil Biology and Biochemistry*, 40, 2634-2642

Thorn K.A., and Cox L.G. (2009). N-15 NMR spectra of naturally abundant nitrogen in soil and aquatic natural organic matter samples of the international humic substances society.*Organic Geochemistry*, 40: 484-499

Tian G., Kang B.T., and Brussaard L. (1993).Mulching effect of plant residues with chemically contrasting compositions on maize growth and nutrients accumulation. *Plant and soil,* 153: 179-187

Tognetti G., Mazzarino M.J. and Laos F. (2008).Compost of municipal organic waste: Effects of different management practices on degradability and nutrient release capacity. *Soil Biology and Biochemistry*. 40, 2290-2296

Vanlauwe B. (2004). Integrated soil fertility management research at TSBF: the framework, the principles, and their application. In Bationo A. (eds) managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Academy science publishers, Nairobi, Kenya

Vanlauwe B., Aihou K., Aman S., Iwuafor E.N.O., Tossah B.K., Diels J., Sanginga N., LyasseO., Merckx R. and Deckers J. (2001). Maize Yield as Affected by organic inputs and Urea in the West African Moist Savanna.*Agronomy Journal,* 93: 1191-1199

APPENDICES

Appendix 1: Experimental layout

BLOCK1	PLOT1 **(T4)**	PLOT2 **(T6)**	PLOT3 **(T1)**	PLOT4 **(T3)**	PLOT5 **(T5)**	PLOT6 **(T7)**	PL0T7 **(T2)**
BLOCK2	PLOT14 **(T1)**	PLOT13 **(T4)**	PLOT12 **(T3)**	PLOT11 **(T5)**	PLOT10 **(T7)**	PLOT9 **(T2)**	PLOT8 **(T8)**
BLOCK3	PLOT15 **(T6)**	PLOT16 **(T3)**	PLOT17 **(T7)**	PLOT18 **(T2)**	PLOT19 **(T5)**	PLOT20 **(T1)**	PLOT21 **(T4)**

Block 1 was near the Main road (Machakos-Wote Road).

The 7 treatments are as listed below:

T1) Control (no organic residue application);

T2) 10 tones/ha compost (Surface application);

T3) 10 tones/ha compost (Incorporated application);

T4) 5tones/ha Maize Stover (Surface application);

T5) 5tones/ha Maize Stover (Incorporated application);

T6) 5tones/ha Maize Stover, 10 tones/ha compost (Surface application);

T7) 5tones/ha Maize Stover, 10 tones/ha compost (Incorporated application).

Appendix 2:Percent carbon changes in the soil and their equivalents in Mg C/ha

Percent carbon changes in the soil and their equivalents in Mg C/ha as a result of different treatment applications at the depth 0-20 cm.

Treatment	**Season 1**		**Season 2**	
	%C change	Equivalent in Mg C/ha	%C change	Equivalent in Mg C/ha
CTRL	-0.07	-0.02	-0.10	-0.03
CS	0.26	0.18	0.43	0.22
CI	0.34	0.20	0.47	0.23
MS	0.63	0.07	0.77	0.12
MI	0.70	0.10	0.83	0.13
MCS	1.20	0.34	1.37	0.38
MCI	1.27	0.36	1.40	0.39

Percent carbon change in the soil and their equivalent in Mg C/ha as a result of different treatment applications at the depth 20-40 cm.

Treatment	**Season 1**		**Season 2**	
	%C change	Equivalent in Mg C/ha	%C change	Equivalent in Mg C/ha
CTRL	0.00	0.00	-0.07	-0.02
CS	0.00	0.00	0.00	0.00
CI	0.80	0.22	0.13	0.04
MS	0.80	0.22	0.10	0.03
MI	0.00	0.00	0.07	0.02
MCS	0.03	0.01	0.03	0.01
MCI	0.13	0.04	0.20	0.06

Appendix 3: Photos of the maize plants under different treatments


REATMENT 6
OMPOST 10,STOVER
5 (S)
REP 2


REATMENT 1
ONTROL
REP 2