KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI, GHANA

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CROP AND SOIL SCIENCES

IMPACT OF SOIL TILLAGE AND SOIL AMENDMENT ON SOIL CARBON SEQUESTRATION, CO2 EMISSION AND MAIZE YIELD

BY

MURPHY ACHEAMPONG OPOKU

BSc. AGRICULTURE (HONS)

AUGUST, 2015.

IMPACT OF SOIL TILLAGE AND SOIL AMENDMENT ON SOIL CARBON SEQUESTRATION, CO2 EMISSION AND MAIZE YIELD

A thesis submitted to the School of Graduate studies, Faculty of Agriculture, College of Agriculture and Natural Resources, Kwame Nkrumah University of science and Technology, Kumasi, Ghana, in partial fulfilment of the requirements for the award of degree of

MASTER OF PHILOSOPHY

IN

SOIL SCIENCE

BY

MURPHY ACHEAMPONG OPOKU

BSc. AGRICULTURE (HONS)

AUGUST, 2015.

DEDICATION

I dedicate this work to my parents, (Mr. and Mrs. Opoku Manu), my late Aunt Margaret, my siblings (Juliana Opoku Manu, Edward Opoku Manu, Lucy Frimpomaa, Raphael Dwomfour Boahen and Theresa Paul Amoakowaa), friends and the Pax Romana Choir KNUST family.

DECLARATION

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

Acheampong Opoku Murphy	………………………….	…………………..
(Student)	Signature	Date

Certified by:

Adjei-Gyapong Thomas	………………………….	…………………..
(Supervisor)	Signature	Date
Rev. Professor Mensah Bonsu	………………………….	…………………..
(Co supervisor)	Signature	Date

Certified by:

Dr. E. A. Osekere	………………………….	…………………..
(Head of Department)	Signature	Date

ACKNOWLEDGEMENTS

Great is thy Faithfulness, Great is thy Love for me, I will forever sing Your praises God, Great is thy faithfulness. Your grace and mercy has brought me thus far. God Almighty, I am grateful for your Love. Nothing more than your love has seen me through to this stage. God, Thank you.

I would also like to thank Alliance for Green Revolution in Africa (AGRA) for the scholarship without which, this study would not have been a reality. I would also like to express my gratitude to Mr. Thomas Adjei-Gyapong, my supervisor for his immense contributions and constructive criticisms which helped shape this work. God bless you Sir. I thank so much, Rev. Fr. Professor Mensah Bonsu, my co-supervisor and father for his contributions and his fatherly love motivated me and will continue to motivate me to greater heights.

I am particularly indebted to Dr. Edward Yeboah of Soil Research Institute for his input and most importantly his willingness to assist me each time I needed his guidance. God bless you Sir. I would like to acknowledge the contributions of Messrs. Joe Acquah and George Nortey, laboratory staff of the Department of Crop and Soil Sciences for their assistance during the laboratory analysis.

A big thank you to my parents, Mr. and Mrs. Opoku Manu and my siblings for their prayers and words of encouragement. I want to also thank all my friends especially Henry Tuffour, Melenya Caleb, Chizoba Uchuno, Badu Mavis, Abigail Tutuaa Amissah and Patricia Abbam. Thanks so much for your unreserved contribution.

My final appreciation goes to others who journeyed with me through this research work, God richly bless you.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPEDIX

LIST OF ABBREVIATIONS

CRI	Crop Research Institute
CSIR	Council of Industrial and Scientific Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CT	Conventional Tillage
CTIC	Conservation Tillage Information Center
CV	Coefficient of Variation
ECEC	Effective Cation Exchange Capacity
FAO	Food and Agriculture Organization
H	Hoe
IPCC	Intergovernmental Panel on Climate Change
IRGA	Infra-red Gas Analyzer
LSD	Least Significant Difference
NT	No tillage
OECD	Organization of Economic Co-operation and Development
PH	Plough Harrow
PP	Plough Plant
RCBD	Randomized Complete Block Design
SOC	Organic carbon
SRI	Soil Research Institute

ABSTRACT

Tillage practices and soil amendments are important technologies in crop production but their influence on yield and soil organic carbon dynamics are diverse with some findings seemingly controversial. A study was conducted at a site that had received same treatments for three years at the Agricultural Research Station of the Kwame Nkrumah University of Science and Technology (KNUST), Anwomaso. A 4x4 factorial experiment in a Split-plot design with three replications (blocks) was used. Four tillage practices: no-till (NT), hoe tillage (H), plough plant (PP) and plough and harrow tillage (PH) were the main plots and four soil amendments 3 t/ha poultry manure (PM), 60-40-40 NPK (NPK), 1.5 t/ha poultry manure plus 30-20-20 NPK (HR) and no amendment (NA) were the subplots. Soil samples were taken from the top soil (0-15 cm) and sub soil (15-30 cm) depths. Carbon stocks was determined within fractionated soil aggregates separated by wet sieving. The relative proportion of aggregate fractions and carbon stock per aggregate fraction was in the order of Large macroaggregates (LM) > small macroaggregates (SM) > Microaggregates (M) > Silt and clay fraction (S+C) within the 0-15 cm depth and small macroaggregates (SM) > Large macroaggregates (LM) > Microaggregates (M) > Silt and clay fraction (S+C) within the 15-30 cm depth. Tillage effect on carbon stocks (total stocks in all aggregate fractions) was in the order of NT (45.31 t C/ha) > H (37.13 t C/ha) > PP (31.10 t C/ha) > PH (14.73 t C/ha) in the topsoil (0-15 cm) and PP (31.38 t C/ha) > NT (31.15 t C/ha) > H (29.96 t C/ha) > PH (26.38 t C/ha) in the subsoil (15-30 cm). The most stable soil carbon stock which occurs in the microaggregate fraction (0.053 – 0.250 mm) was highest in PP (18.12 t C/ha) and was significantly different from NT (15.69 t C/ha), H (15.51 t C/ha) and PH (12.12 t C/ha) over 0-30 cm depth. NT and H were similar in the carbon stock in microaggregate but significantly different from

PH. Soil amendment did not have significant effect on carbon stocks within the various soil aggregates. The tillage-soil amendment interactive effect on carbon storage in microaggregates was highest in PP/PM and was significantly higher than all other combinations except PP/NPK and PP/ HR. Carbon dioxide emission was significantly higher in NT plots (8.36 g C/m^2/day) and NPK amended plots (8.11 g C/m^2/day) than other tillage practices (PH=7.88 g C/m^2/day, PP=7.67 g C/m^2/day, H=7.23 g C/m^2/day) and soil amendments (NA=7.86 g C/m^2/day, PM=7.81 gC/m^2/day, HR =7.36 g C/m^2/day). The Combined effects H/ HR and PP/PM which recorded 6.28 and 6.42 g C/m^2/day respectively, had significantly lower carbon dioxide emissions whereas NT/NPK (8.88 g C/m^2/day) and NT/PM (8.66 g C/m^2/day) had higher carbon dioxide emission. In the major season, tillage effect on maize grain yield was highest under No till (4.12 t/ha) followed by PH = 3.28 t/ha, PP = 2.85 t/ha and H = 2.33 t/ha. Soil amendments effect was highest under HR soil amendment (3.47 t/ha) followed by PM = 3.37 t/ha, NPK = 3.29 and NA = 2.46. Similar trend was observed in the minor season. Plough plant showed potential of sequestering.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Concerns about global warming and climate change, led by the increasing amounts of atmospheric greenhouse gases especially CO_2 have enhanced the interest of soil carbon sequestration as an aspect of counterbalancing human caused CO_2 emissions (Ussiri and Lal, 2009). An increase of 0.88^{o}C has been recorded since the 19th Century (IPCC, 2007). Greenhouse gases involved in global warming include methane (CH_4), Nitrous gas (N_2) and carbon dioxide (CO_2). Carbon dioxide is important among the greenhouse gases contributing approximately 60% to greenhouse effect of global warming (IPCC, 2007).

There are several sinks for carbon storage including geologic formations, biotic, soil and oceanic sinks. The soil functions however as both a source and a sink of greenhouse gases depending on land use and soil management (Ussiri and Lal, 2009). Carbon dioxide emissions from soil and biotic carbon pools also results in atmospheric carbon dioxide increase and a historic carbon emission of 55000-100000 tons from the soil has been recorded (IPCC, 1995)

Atmospheric carbon are stored into the soil as soil organic carbon (SOC) by a process known as carbon sequestration. Soil organic carbon (SOC) and sequestration of atmospheric carbon has a major impact on long-term environmental sustainability of crop production system because SOC influences soil quality, affecting the soil fertility and functions (Robertson, 2008).

Maintaining SOC levels in the soil depends on a host of factors, included are climatic factors (temperature and precipitation), cropping systems, soil type, fertilizer application, type and amount of crop residue left the on soil surface, crop residue management and tillage (OECD, 1999).

Tillage affects a range of biological, physical and chemical properties of the soil. It alters soil organic manure decomposition environment and often results in CO_2 emission (Oorts *et al*., 2007). Soil organic carbon decomposition is higher in tropical soils and as such contributes more to atmospheric CO_2 concentration relative to temperate soils because of higher annual temperature. CO_2 release into the atmosphere has been stated severally by Lal (1995; 1996; 1997) to be accelerated by erosion, leaching of cations, compaction and biotic activity which are aggravated mostly by tillage practices. Also, Tillage and residue management influences CO_2 emission from the soil. Conservation tillage has been recommended because of these challenges with tillage practices (Fernandez *et al*., 1993; Osozawa and Hasegawa, 1995). Conservation tillage is one of the recommended practices for increasing SOC pool in agricultural ecosystems (Lal and Kimble, 1997; Lal *et al*., 1998). Paustian *et al*. (1997) also stated that Nitrogen fertilization leads to increase in Carbon input from enhanced productivity and crop residue return to the soil.

1.2 Problem Statement and justification

Several advances have been made to explain the relationship between various conventional tillage practices and carbon sequestration. However, there are some conflicting findings. Generally, most authors state that conventional tillage stores less carbon in the soil than conservational tillage practices. Angers and Eriksen-Hamel (2008) concluded differently, that soil variables do not affect tillage effects on soil carbon sequestration. Similar contradictions were mentioned by Kessavalou *et al*. (1998a) with soil CO_2 emissions describing it as complex and highly variable.

Hendrix *et al*., (1988) reported higher CO_2 emissions for a 6 year no-tillage soils than for conventional tillage under sorghum and soyabean during an 18-month monitoring period, but, the increase in no-tillage soil could not be accounted for. Similar findings were made by Franzluebbers *et al*. (1995b), Fortin *et al*. (1996) and Aslam *et al*. (2000)

Alvarez *et al*. (2001) and Al-Kaisi and Yin (2005), observed that, during a short period after tillage disturbance, there was lower CO_2 emissions from no-tillage than conventional tillage. There are limited information on the impact of soil amendment and carbon sequestration and CO_2 emission and the few studies even share conflicting ideas. Oladipo *et al*. (2010) observed in Nigeria that increasing poultry manure application reduced CO_2 evolution from the soil but CO_2 emission increased with poultry manure on a no-tillage plot elsewhere (Heller *et al*., 2010). In another study, Subhadip *et al*. (2010) observed that the combine effect of farm yard manure and NPK increased CO_2 accumulation in the soil. There also appears to be limited information on the combined effect of tillage and soil amendments on carbon sequestration especially under maize production.

Maize is one of the most important crops in Ghana accounting for 50-60% of total cereal production. Various amendment programs and tillage practices adopted by farmers to increase maize yield have potential of increasing CO_2 emission from soils, respiration from plants and microbial activities. Agriculture is known to contribute at least 1% to global CO_2 emissions. It is therefore important to assess the environmental friendliness. Owing to the various differences observed in the outcome of studies on carbon storage and emission at various sites, it is important to evaluate carbon storage and emission in specific soils in Ghana.

1.3 Objectives

The main objective of the study was to access the impact of different tillage practices and soil amendments on Carbon dynamics in the soil.

The specific objectives were

i. To determine the effect of tillage and soil amendment on carbon storage.

ii. To evaluate the impact of tillage and soil amendments on CO_2 emission

iii. To measure yield of maize under different soil amendment and tillage practices

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil Organic Carbon (SOC)

Soil carbon exists in organic and inorganic forms, however, majority of the carbon in the soil are in the organic forms. Soil organic carbon is the carbon associated with soil organic matter (Milne and Heimsath, 2009). Soil organic carbon can be grouped into 3 pools or fractions; the labile pool, slow pool and the inert pool and indicated that it is an essential soil property that influences the chemical, physical and biological fertility of the soil (Milne and Heimsath, 2009).

2.1.1 Functions of SOC

Soil organic carbon is the energy source for microbial activity and also precursor to nutrient availability through mineralization. The active/labile SOC forms are the major microbial energy source as well as nutrient source. The humic fraction functions as participant in aggregate stability, water holding capacity, improvement of the soil and nutrient holding capacity. (Edwards *et al*., 1999). The effect of SOC on aggregate stability has direct effect on reduced soil erosion, making the soil resistant to mass movement by runoff water. The increased infiltration and water holding capacity induced by SOC reduces overland flow, help recharge groundwater and increase water availability to crops. Subsequently, SOC is a measure of greater crop productivity (IPCC, 2000; 2003; 2006; Ruddiman, 2007; Lal, 2008; Pan *et al*., 2011; FAO, 2012)

A healthy soil, that support a sustainable production system, is defined by Govaerts *et al*. (2008) as the continued capacity of the soil to sustain biological productivity, maintain quality of air and water environments and promote plant, animal and human health and soil organic carbon is the basis of soil health (Leu, 2007).

2.1.2 Factors affecting Soil Organic Carbon

Several factors and conditions affect SOC loss and storage in the soil. The various processes that influence SOC dynamics in the soil are controlled by climatic conditions such as rainfall, atmospheric temperature; soil properties and the type of vegetation (Baldock, 2008).

Loss of SOC from the soil results from the breakdown and conversion of soil organic materials to carbon dioxide. It is accelerated by various factors, included are the type organic material, soil clay content, soil management practices, crop residue removal and burning etc. (Baldock, 2008). The most important factor to accelerated carbon loss from the soil is human influence and agricultural systems. It is difficult to accurately measure exact quantities of SOC loss but anthropogenic activities such as burning which remove soil cover and tillage and drainage which expose SOC to oxygen and rapid decomposition are recorded to cause huge SOC loss (Ruddiman, 2007).

Additions of SOC on the other hand depends chiefly on the type and amount of organic matter returned to a cropping system. Thus any crop production system that increases productivity and return crop residue to the soil tends to increase SOC input to the soil as majority of SOC enter the soil as crop residue (Baldock, 2008). Secondly, reduced tillage and no-tillage are mentioned as practices with a potential of increasing SOC storage in the soil.

Directly applying compost, biochar, manure and other organic materials to the soil increases the soil’s potential of SOC storage (Baldock, 2008).

The SOC balance of agro-ecosystems is mainly governed by the difference between C inputs (post-harvest residues, rhizodeposition), and recycled organic materials (manure, slurry or sludge), and SOC output through decomposition of organic matter (Kätterer *et al*., 2012)

According to Baldock (2008), organic carbon stored in the soil is a balance between additions from input of organic material losses through decomposition of organic materials or loss through erosion. Soil organic carbon levels increase with plenty water, nutrients and sunlight and it is low where there is high microbial activity and fallow with no plant additions (Baldock, 2008).

2.2 Carbon Sequestration

Soil carbon sequestrations is the capture and safe storage of atmospheric carbon in the soil that would have either been emitted from the soil or remained in the atmosphere. It is the transfer of atmospheric carbon to long-lived pools and securely keeping them so that it is not easily lost back to the atmosphere by re-emission, accomplished by adaptation of appropriate land management systems (Lal, 2004). The fundamental aim of carbon sequestration is to prevent carbon dioxide emissions emanating from human activity from reaching the atmosphere and removing what has already accumulated in the atmosphere and keeping it in the soil for secured storage (Al-Kaisi *et al*., 2008). The technical potential for this process is higher in degraded/desertified soils and soils that have been managed with extractive farming practices than it is in good-quality soils managed according to recommended management practices (Lal, 2009).

Carbon is stored in the soil under two (2) pools; soil organic carbon pool and soil inorganic pool (Eswaran *et al*., 1995);

The global SOC per 1 m soil depth is estimated at 1550 Pg and the SIC is estimated at 750 Pg (Batjes, 1996). The two pools put together gives approximately 2300 Pg within the top 1m of the soil (Lal, 2004).

Aside the soil pool, the vegetation pool is estimated at 560Pg. The atmospheric pool is estimated at 760 Pg at an increasing rate of 3.2 Pg C/year. Per this statistics, the biotic carbon pool (carbon in the soil pool and vegetation pool) is about 3-4 times more than the atmospheric carbon pool (Raich and Schlesinger, 1992; Schimel, 1995).

According to Lal (2002c), the above mentioned pools are interconnected such that 60 Pg C is exchanged between the vegetation pool and the atmosphere. Ironically, only 6.3 Pg/year and 1.6-2.0 Pg/year carbon is emitted from fossil fuel and land use change respectively. This means that improving photosynthetic fixation and sequestering only 5% of the photosynthetic carbon in to the soil and vegetation carbon pools can greatly offset the industrial emissions (Lal, 2002a).

Lal (2009) comments that soil carbon sequestration is a win-win strategy. It mitigates climate change by offsetting anthropogenic emissions, improves the environment, especially the quality of natural waters, enhances soil quality, improves agronomic productivity, and advances food security. It is a low-hanging fruit and a bridge to the future, until carbon-neutral fuel sources and low-carbon economy take effect.

The potential of soil C sink of a managed system is estimated at 55-78 Gt which represents 50-66% of the possible sink potential of the soil (Lal, 2004). The strategy of storing carbon in the soil is cost effective and environmentally friendly. Carbon sequestered through change of land use (conversion from agricultural land to natural ecosystem) and recommended management practices peaks at 5-20 years after adoption of recommended management practices (Lal, 2004).

2.3 Soil Aggregation and Soil Carbon Dynamics

An understanding in soil aggregate dynamics in relation to SOC storage depends on the functions of plants, microbial population of the soil and the soil itself (Angers and Giroux, 1996). Soil aggregation in relation to microbial activity rests on processes of plant residue breakdown leading to the formation of the “organic mat” for soil aggregation (Watts *et al*., 2001). Also, the role of plants and SOM in soil aggregation is very important in SOC sequestration (Blanco-Canqui and Lal, 2004). Aggregate size, strength, configuration and nature depends on the stabilizing agent.

Macroaggregates are stabilized by microbial polysaccharides whiles micro aggregates are stabilized by humic compounds (Greenland, 1965). Temporary, transient and persistent are the various classes of binding agents responsible for stabilization of soil aggregates. (Tisdall and Oades, 1982).

The temporary class of binding agents including plant roots, fungal hyphae, and bacterial cells are associated with macro aggregates and are highly vulnerable to tillage (Skjemstad *et al*., 1990; Cambardella and Elliot, 1993).

The second class of binding agents (the transient) include polysaccharides, mucilage, and root exudates. These, especially the polysaccharides, mostly bind 10-50 μm aggregates using polymer bridges. They are easily adsorbed by clay relative to humic and fluvic acids (Tisdall and Oades, 1982; Chenu and Guerif, 1991). Tisdall (1996) further explains that they are relatively immobile because of their association with clay (negatively charged surfaces). Because of their reduced mobility, they remain temporary undecomposed as long as they bind clay into macro aggregates. Aggregate stability induced by the second class of binding agents only last a few weeks as they are easily decomposed (Wild, 1988).

Persistent agents include the humic compounds, the polyvalent cations (Ca^{2+}, Mg^{2+}, Fe III, etc.) and polymers. They are the highly decomposed organic materials. These agents are connected to micro aggregation and long term SOC sequestration. (Blanco-Canqui and Lal, 2004). Classical evidence by Edwards and Bremner (1967) reveals that these persistent agents form an inner portion of micro aggregates adsorbed clay particles forming organo-mineral complexes. These compounds have relatively high molecular weight making them recalcitrant. The process of soil carbon storage by aggregates is illustrated in Figure 2.1 below;

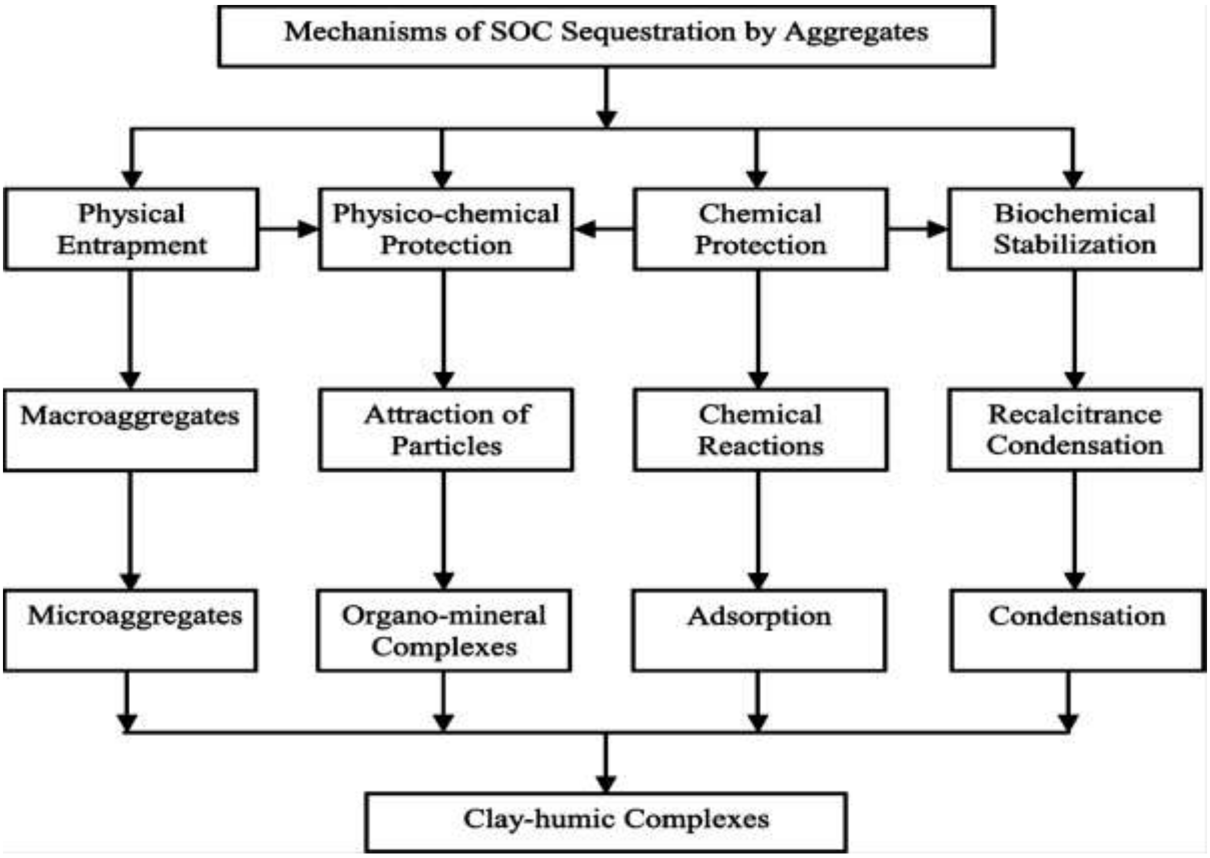


Figure. 2.1. Pathways of soil organic carbon (SOC) sequestration by aggregates

Source: Golchin *et al.*, 1994; Laird, 2001; Six *et al.*, 2002.

2.4 Soil Fractionation

The size of soil aggregates has great influence on conservation and mineralization of carbon. However, the procedure used to separate the soil into respective aggregates (fractionation) may influence levels of aggregate distribution and quantification of carbon pools (Whalen and Chang, 2002; Sainju, 2006)

Wet sieving method of soil aggregate separation is widely used to measure or quantify size distribution and aggregate stability caused by raindrop impact on dry soil causing slaking and surface crusting (Cambardella and Elliot, 1993).

The disadvantages of the wet sieving method include;

i. Rapture of weak aggregates in water during sieving caused by ion hydration, sudden release of internal air pressure, osmotic swelling forces or solubility of binding agents in water (Perfect *et al*., 1990; Gale *et al*., 2000)

ii. Increased disruption of physical habitat of microbial communities (Mendes *et al*., 1999; Schutter and Dick, 2002).

iii. Underestimation of C pools in the aggregate because of exclusion of water soluble C (Seech and Beauchamp, 1988).

Based on these pitfalls, Dry sieving is been advocated for so as to avoid all these disadvantages of wet sieving (Mendes *et al*., 1999; Schutter and Dick, 2002).

Dry sieving however, explained by Kemper and Rosenau (1986), also ruptures aggregates caused by the abrasive action of the sieves such that the average aggregate size is reduce to somewhat below that found in the undisturbed soil. But Mendes *et al*. (1999) as well as Schutter and Dick (2002) quickly argue that the dry sieving may not be as destructive as the wet sieving.

Sainju (2006), had lower amount of the large macroaggregates (> 2mm) and higher amount of the small macroaggregates (2.00 - 0.25 mm). But both was higher than the amount of microaggregates (0.25-0.053 mm) and silt and clay fractions in all samples that were sieved using the dry sieving method. Few exceptions for the 0-5 cm and 5-10 cm aggregates was observed. Large macroaggregates was higher with the dry than with the wet sieving method for all soils.

In the same study, Sainju (2006), observed that the amount of small macroaggregates was higher in wet than in dry sieving for almost all sites studied. The amount of microaggregates and silt and clay fractions between sieving methods varied between soil depths and sites.

The lower amount of large macroaggregates in wet than in dry sieving explained by Sainju (2006); Perfect *et al*. (1990) and Gale *et al*. (2000), was caused by rupture of weak aggregates in water because of ion hydration, sudden release of internal air pressure, osmotic swelling forces, or to solubility of binding agents in water. The Large macroaggregates are especially vulnerable to aggregate rupture by water compared with small macroaggregates which in turn results in an increase in the amount of the other aggregate fractions (small macroaggregates, microaggregates and silt and clay fractions) (Sainju, 2006).

A lower amount of large macroaggregates with dry sieving was observed by Sainju (2006) with samples at the 0-5 cm than at 5-20 cm soil depth. This is explained to be probably due to the use of heavy machinery on the soil surface during tillage practices, mechanical fertilizer application, herbicide application, pesticide application and harvesting (Sainju, 2006). A similar observation was made by Whalen and Chang (2002) in the northern Great Plains.

Also, the higher amount of large macroaggregates by dry sieving could be caused by higher clay content. Increased clay content increases the proportion of macroaggregates in the soil (Franzluebbers *et al*., 2000).

2.4.1 Carbon Pools with Fractionation

SOC is regarded as slow pools if soil carbon changes slowly over time. (Franzluebbers and Arshad, 1997; Franzluebbers *et al*., 1999). Also, mineralizable and microbial biomass C are considered the active pool that change seasonally and influence aggregation. The particulate organic carbon fraction also are considered intermediate pools for changes of soil C with time. It provides substrates for microbes and also influence aggregation (Beare *et al*., 1994a; Franzluebbers and Arshad, 1997; Jastrow *et al*., 1998; Franzluebbers *et al*., 1999; Six *et al*., 1999; Martens, 2000; Gale *et al*., 2000).

According to Six *et al*. (1998), seconded by Whalen and Chang (2002), because the levels of aggregation and aggregate turnover influence soil organic matter, determination of C pools in aggregates provide important information on soil C sequestration and mineralization in aggregate size fractions.

The distribution of C pools among soil aggregates is heterogenous (Miller and Dick, 1995). Some studies report that potential carbon mineralization in the macroaggregates (> 0.25 mm) is higher and greater than in microaggregates with aggregates separated with wet sieving (Franzluebbers and Arshad, 1997). The differences in C pools among size fractions results from soil properties such as clay and organic matter contents as well as clay mineralogy (Franzluebbers *et al*., 2000; Six *et al*., 2000).

Sainju (2006) adds that SOC in aggregates are higher at 0 to 5 cm than at 5 to 20 cm, regardless of sieving methods and locations. Similarly, SOC and POC in aggregates are dependent on the locations sampling was carried out, without regards to sieving methods.

The distribution of SOC among aggregate size fractions determined by dry and wet sieving methods is influenced by cropping systems and soil properties at different locations. Mostly, grassland soils have higher SOC concentration than cropland soils because of continuous plant C inputs from above ground and below ground biomass and reduced rate of mineralization from decreased soil disturbance (Cambardella and Elliott, 1993; Six *et al*., 1998, 2000). It is also possible that some of these C inputs were preferentially sequestered in less than 0.25-mm fractions in grassland soils leading to higher SOC in the less than 0.25-mm fractions than in other fractions separated by dry compared with wet sieving (Sainju, 2006).

Variations in SOC among aggregate size fractions in croplands can also be a result of differences in mineralization rates of soil organic matter caused by destruction of aggregates during tillage, sequestration of C in aggregates during plant growth, and differences in soil properties, such as clay content (Wan and El-Swaify, 1996; Maguire *et al*., 1998; Whalen and Chang, 2002).

In a study, Sainju (2006) observed that the SOC in the large macroaggregates (> 2.00 mm) was higher at 0 to 5 cm by wet than by dry sieving. This was attributed to the preferential conservation of C in large aggregates in no-tilled sandy soil where stored C could be determined only when aggregates were separated by wet sieving. Contrary, higher SOC in less than 0.25-mm fractions at 0 to 5 cm by wet than by dry sieving suggested that C could be stored preferentially in microaggregates and silt and clay fractions in tilled soil with higher clay content, where stored C could be determined when aggregates were separated by wet sieving (Sainju, 2006).

It is obvious to observe higher SOC concentrations in aggregates at the 0-5 cm than at the 5-20 cm depths because of increased plant residue addition at the soil surface (Sainju, 2006).

Higher SOC in aggregates can also be linked to higher clay content because increased clay content is usually associated with high organic matter concentration (Franzluebbers *et al*., 2000; Six *et al*., 2000; Sainju, 2006).

Sainju (2006) concluded that soil aggregate size distribution and C pools in aggregates vary between dry and wet sieving methods depending on soil properties and cropping systems. However, dry sieving of moist soil is as good as wet sieving in determining soil aggregation, active and slow C pools. Regardless of sieving methods, soil properties, and cropping systems, most of the C pools are stored in microaggregates and silt and clay fractions compared with large and small macroaggregates (Sainju, 2006).

2.5 Carbon Dioxide Emission

Anthropogenic activities in agriculture particularly with soil conditioning and soil or land use conversion influences the soil property of either a source or sink of atmospheric carbon (IPCC, 2000). Soil management practices (soil tillage and fertilizer application) which improves agricultural production affects the attributes of the soil to either sequester or otherwise increase atmospheric carbon.

Curtin *et al*. (2000) reported that no-tillage which is an aspect of soil management reduce the soil carbon flux and rather sequester more atmospheric carbon.

Carbon dioxide is produced naturally in the soil from various soil processes. These include decomposition of organic materials in the soil which results from the heterotrophic respiration of soil macro and microorganisms and soil fauna and also from plant root respiration. (Nyakatawa *et al*., 2012).

The amount of carbon dioxide evolved from the soil varies from region to region and within management practices. Carbon emission can be as high 10-15 times that released by combustion of fossil fuel (Raich and Schlesinger, 1992; Smith *et al*., 2003). Jinyan and Chuankuan (2006) adds that a small change in global soil respiration can significantly affect atmospheric carbon concentration.Even though soil carbon efflux is a natural phenomenon, it is influenced by activities such as land use conversion, cultivation and fertilizer application and organic manure management (Nyakatawa *et al*., 2012).

According to Nyakatawa *et al*. (2012), it is rather these soil processes that activates or create conducive conditions for environmental variables such as soil temperature and moisture to significantly affect the behaviour of soil microbial activity and soil carbon dioxide fluxes. This means that the behaviour of agricultural soils as either a source or sink of atmospheric carbon dioxide is a manifestation of the net effect of the interactive processes driving its biological, chemical and physical properties (Nyakatawa *et al*., 2012).

Xu and Qi (2001) adds that soil respiration is the major components of the ecosystem carbon balance and it contributes 50-95%of total ecosystem respiration.

2.5.1 Soil Temperature and Soil Moisture

Soil temperature and moisture conditions influence rate duration and extent of biological, biochemical and biophysical soil reactions which impact soil-atmospheric gas exchange. Soil temperature and soil moisture conditions have been reported to significantly influence soil efflux rates (Reth *et al*., 2005; Lee *et al*., 2007; Heller *et al*., 2010).

Wang *et al*. (2010) revealed that diurnal changes in soil carbon dioxide flux were closely related to air and soil temperature changes. Smith and Owens (2010) discovered through simulated rainfall that surface applied poultry manure emitted high carbon dioxide right after the rains.

A study by Nyakatawa *et al*. (2012) had no significant difference between various tillage systems. Soil disturbance, usually modifies soil temperature, hence it is mostly expected that soils disturbed through tillage practices are to have higher soil temperature than less disturbed soils.

He also observed that a similar trend with soil moisture with the various tillage systems as the moisture content for the conventional and conservational (No-tillage) tillage systems were not significantly different.

2.5.2 Effect of Soil Temperature, Soil Moisture Content on Carbon Dioxide Emission.

Nyakatawa *et al*. (2012) observed a significantly positive correlation ($p < 0.001$) between soil carbon flux, soil temperature ($r = 0.18$) and soil moisture content ($r = 0.22$). Soil temperature can account for 65% of soil carbon dioxide flux variability compared to 5% for soil moisture and 3% for air temperature (Rey *et al*., 2002).

The positive correlation between soil carbon dioxide emission with temperature and soil moisture content has been reported by other authors. Raich and Schlesinger (1992) reported that the release of carbon dioxide from the soil organic matter by heterotrophic respiration and the release by autotrophic root respiration generally increases exponentially with temperature.

Smith *et al*. (2003) also argues that, the release of carbon dioxide by aerobic respiration is a non-linear function of temperature over a wide range of soil moisture contents but becomes a function of water content as the soil dries out.

In occasions where seasonal changes in soil moisture content are small, soil temperature is most found as a major factor controlling carbon flux (Mielnick and Dugas 2000; Frank *et al*., 2002). Almaraz *et al*. (2009) found different seasonal emission patterns of carbon dioxide fluxes with higher mid-season fluxes which were related to temperature.

Apart from soil temperature and moisture effects, there is an increase in soil mineral activity and root growth which contributes to soil carbon efflux. With low water content and lower temperature, microbial activity is low and lack of root vitality leading to the decline or fall in carbon efflux.

2.5.3 Measuring Soil Carbon Dioxide Emissions

Production of CO_2 in the soil results from the oxidation of soil organic matter by heterotrophic microorganisms and the respiration of plant roots. Soil respiration is an important aspect of soil quality and an indicator of soil fertility (Jensen *et al*., 1996; Staben *et al*., 1997). Soil respiration has been widely used for many years to quantify the impact of soil microbial activity of various management inputs (Haney *et al*., 2008). The purpose of many carbon flux studies are geared towards understanding these natural processes of rates of C mineralization (Haney *et al*., 2008).

Soil respiration is a major component in global carbon cycle and it is greatly controlled by residue inputs (Jensen *et al*., 1996). CO_2 efflux from soil respiration is a major contributor to net carbon exchange in terrestrial ecosystems second only in magnitude to photosynthesis by plants (Rustad *et al*., 2000).

There are various uncertainties with CO_2 efflux measurements which is attributed to the methods of measurement. (Raich and Schlesinger, 1992). Furthermore, uncertainties in measuring soil CO_2 fluxes can cause significant errors in estimating net ecosystem exchange. Predicted effects of climate change need to encapsulate the effects of changes with temperature and moisture conditions on release of CO_2 from terrestrial carbon pools particularly soil. In regional and global terms, a small change in CO_2 efflux can represent a large change in carbon flux from the land (Raich and Schlesinger, 1992; Rochette and Hutchinson, 2005).

The ability to accurately measure and quantify soil CO_2 flux in Situ is of paramount importance in aiding the improvement of our conceptual understanding of soil organic matter turnover (Hansen *et al*., 1991). In the soil on the field, transport of carbon dioxide produced is controlled by soil porosity, water content and tortuosity of soil matrix (Simunek and Suarez, 1993).

Selecting a technique therefore for measuring soil CO_2 efflux a major issue in the study of terrestrial carbon cycling (Raich and Schlesinger, 1992; Rochette and Hutchinson, 2005).

2.5.4 Methods for CO_2 Efflux measurement

Several methods have been used to measure soil CO_2 emission. The choice of method or procedure is guided by;

i. Need for spatial and temporal sampling

ii. Resource and equipment available

iii. Accuracy required for the measurement

iv. Assumptions and measurement artefacts

v. Evidence that the method can be applied reliably on the field

(Norman *et al*., 1997; Lund *et al*., 1999).

There are several methods for measuring and quantifying soil carbon emission. These include a classical method introduced by Lundegård (1927) which uses a static closed changer and passive absorption of CO_2 in an alkali trap for about 24h. (Edwards, 1982; Buyanovsky *et al*., 1986; Beyer, 1991; Franzluebbers *et al*., 1995).

This method is extensively used. However, its accuracy has been challenged when compared to other methods such as the dynamic methods where chamber air is actively supplied to an infra-red gas analyzer (IRGA) (Raich *et al*., 1990; Rochette *et al*., 1992; Nay *et al*., 1994).

Another method is the NFTSS (Non-Flow through steady-state) chamber technique which uses chemical absorption by soda lime. This method appears to be most practical method for field measurements. It is comparatively inexpensive and simple. It can also be used for a wide range of locations. The measurement expands for 24 hours allowing good temporal integration (Keith and Wong, 2006).

Previous studies have found results from different methods correlated, but often with discrepancies, non-linearity, and site specificity (Rochette *et al*., 1992; Nay *et al*., 1994; Haynes and Gower, 1995; Jensen *et al*., 1996; Norman *et al*., 1997; Janssens and Ceulemans, 1998; Le Dantec *et al*., 1999; Janssens *et al*., 2000; Pumpanen *et al*., 2004).

2.6 Tillage Practice

Soil tillage is the loosening of the soil by turning the soil to prepare soil for planting. Lal (1983) defines tillage as a physical, chemical or biological soil manipulation to optimize conditions for germination, seedling establishment and crop growth. Ahn and Hintze (1990) also defines tillage as physical loosening of the soil which is done within a range of cultivation operations either by hand or mechanized. Tillage is a widely used practice for weed control, seed bed preparation, soil conditioning and soil physical condition improvement (Franzluebbers, 2004).

Tillage practices are grouped under two broad headings, conventional (ploughing, harrowing) and conservational tillage practices (no-tillage, minimum tillage, reduced tillage) (CTIC, 2002). Conventional tillage applies one or more passes on the field, bury residue into the soil and leave the soil surface bare and unprotected. Tillage practices that restrains or confines most of the crop residue on the surface and involves minimal tillage is known as conservational tillage (Murphy, 2005). The type of tillage practiced has immense contribution on the carbon storage or emissions in/from the soil. (Lal *et al*., 1998; Gale and Cambardella, 2000; Lal, 2002b). Conservation tillage is defined as any tillage and planting system that maintains at least 30% of soil surface covered by residue after planting to reduce water erosion (CTIC, 2002).

2.6.1 Effect of Tillage Practices on Carbon Sequestration

Several authors argues that, conservation tillage conserves organic matter and stabilizes aggregates and consequently increase organic carbon pools and that conservation tillage promotes carbon enriched macro aggregation. This is possible because conservation tillage, particularly no-tillage, impact less perturbation to the soil characterized with low micro aggregate turnover unlike conventional tillage practices (Skidmore *et al*., 1986; Gale and cambardella, 2000; Six *et al*., 1999a; 2000; Yang *et al*., 2013). McConkey *et al*. (2003) estimated about 67-512kg C ha^{-1} yr^{-1} more carbon sequestered by no-tillage than conventional tillage.

Many researchers (Johnson *et al*., 2005; Liebig *et al*., 2005; Franzluebbers, 2005; Franzluebbers and Follett, 2005; Lal *et al*.,1998; Kumar *et al*., 2012) have suggested that converting from conventional tillage systems to conservational tillage systems e.g. no-till has a large potential for SOC sequestration, but NT does affect the distribution of SOC within the soil profile (VandenBygaart *et al*., 2003; Sundermeier *et al*., 2005; Baker *et al*., 2007; Luo *et al*., 2010; Ogle *et al*., 2012). When No - Till, and conventional tillage are under a non-steady state (Olson, 2010) all three tillage systems may fail to sequester a significant amount of SOC.

According to Six *et al*. (2000), more plant residue left on no-tillage plots than conventional tillage plots increases biological activity resulting in greater macro and micro aggregation which in turn shelter SOC within the aggregates physically.

Another meta-analysis found that crop productivity can be reduced with adoption of no-till, particularly in cooler and/or wetter climatic conditions (Ogle *et al*., 2012). Besides crop yields, crop harvest index (ratio of harvested yield to the amount of crop aboveground residue remaining in the soil) plays another key role in the quantity of crop residues returned to the soil.

No-tillage plots may have twice more stable and free micro aggregates than conventionally tilled plots resulting in increased SOC encapsulation in the micro aggregates because of slow macro aggregate turnover (Six *et al*., 2000). In the case of conventional tillage such as ploughing, harrowing, ridging, etc. there is increased soil turnover exposing most macroaggregates to microbes. Residue decomposition is accelerated leading to less amounts of SOC stored. It also disturbs soil aggregation (Bossuyt *et al*., 2002; Six *et al*., 2000; Lal, 2002c).

Also, continuous tillage leads to less stable micro aggregate formation. Continuous disturbance of the soil causes cessation of SOC and soil structure interaction which results in micro aggregates with depleted C being formed (Puget *et al*., 1995; Blanco-Canqui and Lal, 2004). Conventional tillage mostly adversely affect macro aggregates more than micro aggregates. Tillage effects on degradation of macro and micro aggregates is selective as micro aggregates often remain relatively intact during tillage, because the binding agents for micro aggregation are highly resistant (Tisdall and Oades, 1982; Beare *et al*., 1994a; Six *et al*., 1999b; Denef *et al*., 2001; Bossuyt *et al*., 2002). Angers and Chenu (1998) and Six *et al*. (1999a) concluded that soil organic carbon sequestration was a function of the soil structure stability hence soils with less disturbance tends to enhance soil organic carbon storage. Yang *et al*. (2013) cautions that many soil C studies have indicated that the impacts of NT on soil C sequestration are compounded by many factors and should not be generalized.

2.6.2 Effect of Tillage on Carbon Dioxide Emission

A study conducted by Nyakatawa *et al*. (2012), showed that carbon dioxide emission between various tillage practices had no significant difference between no-till and conventional tillage in winter, however there was a significant difference during summer. During spring where rainfall amount is high, no-till recorded higher carbon (7.7 kg C ha^{-1} day^{-1}) than conventional tillage (6.9 kg C ha^{-1} day^{-1}) by 0.8 kg C ha^{-1} day^{-1}.

In another study, (Reicosky and Lindstrom 1993; Prior *et al*., 2000), soil emission in conventional tillage during summer was 94% greater than no-till. The high carbon dioxide emission recorded from the conventional tillage in summer was explained to be due to increased air space after tillage which positively support carbon emission from the soil.

Tillage exposes the soil capillary stream to the atmosphere, promoting mass movement of soil air from soil to the atmosphere (Nyakatawa *et al*., 2012).

Bauer *et al*. (2006) reported that, the difference of soil carbon dioxide fluxes between conventional and conservational tillage tends to be greater during summer and spring than in fall. On the contrary, Prior *et al*. (2000) reported that disturbing the soil results in high carbon dioxide efflux in fall but not in spring.

On the average, Nyakatawa *et al*. (2012) recorded 36% more carbon dioxide emission from conventional tillage soil than the no-till plots. Johnson *et al*. (2010) states that carbon dioxide flux increases briefly following tillage, but the impact of tillage was negligible when carbon flux was integrated across the year.

Lower organic C contents in tilled compared to no-tilled surface soils have been often attributed to greater CO_2 emissions in the former, especially after tillage operations as the carbon would be mixed into the soil and the soil would be aerated (Reicosky and Lindstrom 1993; Reicosky *et al*. 1997). However, more CO_2 emissions from mouldboard plough than from no-till soils are generally based on short-term fluxes (typically over a growing season), but not necessarily over an annual basis (Fortin *et al*., 1996). On a yearly basis, ploughing the soil appears to affect the time of CO_2 release rather than the amount of CO_2 produced when compared to no-till practices (Hendrix *et al*. 1988). Yearly CO_2 emissions were also found higher in no-till than in tilled soil (Franzluebbers *et al*. 1995; Alvarez *et al*. 1998). In soils under maize wheat rotation, the cumulated CO_2 over the 331 days of measurement were 31609 269 and 40649138 kg CO_2-C ha^{-1} from conventional and no-tilled plots, respectively, and the authors believed that a large proportion of the CO_2 emissions in no-till was probably due to the decomposition of old weathered residues (Oorts *et al*. 2007). Although no-till cropping systems may protect carbon through less soil disturbance (Reicosky and Lindstrom 1993) and increased aggregation (Six *et al*. 2000) relative to conventional tillage, CO2 emissions in no-till and conventional tillage systems vary with soil climatic conditions and the amounts and location of crop residues and soil organic matter. Thus, the concept that no-till practices always protect SOC from mineralization relative to ploughing should not be generalized (Yang *et al*., 2013) No-tillage effect on CO_2 emission rates depends on the soil type as Feiziene *et al*. (2012) discovered lower CO_2 emission in sandy soil but had no significant effect in a loamy soil.

According to La Scala *et al*. (2006), the degree of soil carbon emission from the soil depends on magnitude of soil perturbation. Several studies have described relatively higher soil carbon emission under conventional tillage than under conservational tillage particularly no-tillage (Al-kaisi and Yin, 2005; Reicosky *et al*., 2005; Chatskikh and Olesen 2007; Chatskikh *et al*, 2008).

Elder and Lal (2008) stated no significant difference between carbon emission under conventional and conservation tillage practices particularly mouldboard ploughing, no-tillage and bare fallow. Hendrix *et al*. (1988) measured high carbon flux on no-tillage plots more than conventionally tilled plots.

In another study, conventional tillage increased CO_2 flux 94% more than no-tillage during summer but recorded no significant difference between the tillage practices with spring, fall and winter seasons (Nyakatawa *et al*., 2012). Johnson *et al*. (2010) reported that soil carbon flux in conventionally tilled soils are significantly different from no-tillage soils when the soil has been freshly tilled. Subsequently, the difference in soil carbon flux becomes non-significant. The increase of soil carbon flux in conventionally tilled soils has been reported by several authors (Reicosky *et al*., 2005; Prior *et al*., 2000) to be as a result of increased soil air space leading to heightened movement of gases (CO_2) from soil to the atmosphere. Carbon emission vary with seasons.

2.7 Soil Amendment

A soil amendment is any material added to a soil to improve its physico-chemical properties, such as nutrient levels, drainage, aeration and structure improve soil environment for plant growth (Nobuhisa and Hiroyuki, 2009).

There are two broad categories of soil amendments: organic and inorganic. Organic amendments come from something that was once alive. Inorganic amendments, on the other hand, are either mined or man-made. Organic amendments include sphagnum peat, wood chips, grass clippings, straw, compost, manure, biosolids, sawdust and wood ash. Inorganic amendments include vermiculite, perlite, tire chunks, pea gravel and sand (Nobuhisa and Hiroyuki, 2009). Organic amendments increase soil organic matter content and offer many benefits. Over time, organic matter improves soil aeration, water infiltration, and both water- and nutrient-holding capacity. Many organic amendments contain plant nutrients and act as organic fertilizers. Organic matter also is an important energy source for bacteria, fungi and earthworms that live in the soil. Nobuhisa and Hiroyuki (2009) noted that manure increase soil organic carbon in two dimension; as direct source of carbon input to the soil and increase in above ground residue carbon and concluded that tillage practices had no effect on carbon storage but rather, crop management.

2.7.1 Manuring Against N-Fertilizer in Sequestering Carbon

According to Lal (1998), the primary principle to carbon sequestration increase dwells on replenishment of nutrients especially N which enhance biomass production and convert cropland residue into humus. The mostly recommended soil amendments for nutrient replenishment are organic manure and inorganic fertilization to keep the soil nutrients at optimal levels for plant growth.

These amendments contributes differently to carbon sequestration. Most of the studies compare organic manure to inorganic fertilizer in terms of carbon sequestration showed a more positive results on the side of organic manure than inorganic fertilizer. These studies showed that organic manure sequesters more carbon than inorganic fertilizers (Jarecki *et al*., 2005; Yang *et al*., 2004; Matthews and Pilbeam, 2005; Hati *et al*., 2006; Morari *et al*., 2006; Rudrappa *et al*., 2006; Su *et al*., 2006). In another study, several amendments were compared and the manure application appeared to sequester more carbon (392 kg C ha^{-1} yr^{-1}) than the remaining amendments especially the inorganic fertilizer (355 kg C ha^{-1} yr^{-1}) (Jarecki *et al*., 2005).

Similarly, a long term study showed a general decline in nutrients supply and hence less carbon sequestration. However, the manure application emerged the highest sequester of carbon (Rasmussen and Parton, 1994; Rasmussen *et al*., 1998).

Although manure increases carbon sequestration, many farmers are aware of the difficulty of its application and the quantity to be supplied to raise soil nutrient status. Follett (2001), discovered that a site supplied with 97 kg N ha^{-1} yr^{-1} inorganic N-Fertilizer could sequesters 6-18 MMT C yr^{-1} on a 119 Mha of land whereas 250kg N ha^{-1} yr^{-1} manure supplied to same land area sequestered 3.6-9 MMT C yr^{-1}. The difference in C sequestered was attributed to the uniform spread of inorganic fertilizer whereas the organic manure covered a very small area of 18 Mha of the total land area. Olson *et al*. (2014) highlights that, carbon inputs from outside a land unit, such as animal waste or other C sources, are considered to be a redistribution of C already in storage and from external sources and not sequestered SOC. These C rich amendments need to be accounted for when they are applied to the land unit.

2.7.2 Poultry Manure and Carbon Dioxide Emission

Soil amendment such as poultry manure is a renewable nutrient source which plays an important role in promoting environmental and economically sustainable agricultural practices. It is basically composed of fowl dropping and bedding material. It is a valuable source of plant nutrients and also an excellent soil amendment for improving soil quality and productivity.

Use of poultry manure has gained popularity due to the prices of inorganic fertilizer. It is also another avenue to dispose of such waste which is non-essential in the poultry farm or in animal production (Nyakatawa *et al.*, 2001a; Nyakatawa *et al.*, 2001b; Sainju *et al*., 2006). Ill-handling of poultry manure leads to increased emission of greenhouse gases (Sommer and Hutchings 2001; Rochette *et al*., 2004; Sharpe *et al*., 2004). Organic waste (crop residue and manure) contributes to high carbon dioxide emissions relative to inorganic fertilizers (NPK) (Hadas *et al*., 2004; Jones *et al*., 2005; Ding *et al*., 2007.

The process of carbon loss from the soil is based on microbial respiration and dissolution of carbonates in calcerous soils (Rochette *et al*., 1999). Addition of NPK and manure to semi-arid soil which is normally low in soil organic matter triggers increased carbon dioxide emission to the atmosphere (Schlesinger, 1999).

The emissions of carbon dioxide caused by soil amendment is controlled by the organic material, soil temperature, soil moisture, soil type, vegetation and quantity and quality of organic amendments (McLain and Martens, 2006). Carbon dioxide emission is controlled by biological production of carbon dioxide and gas diffusivity. (Bertrand *et al*., 2007; Johnson *et al*., 2007)

A study by Heller *et al*. (2010) measured high carbon emissions on poultry manure amended plots. The peak emission was measured after poultry manure was applied. Tilled plots that received poultry manure emitted less carbon dioxide relative to the no-till plots. Poultry manure amended soils releases more carbon dioxide than other soil organic amendments (Heller *et al*., 2010)

A regression analysis showed that NH_4^+ contributed 39% of carbon flux variability in various plots tested (Heller *et al*., 2010). The relation could be attributed to the relationship between labile carbon in the organic residue or material and mineralized

N in the soil. In addition, mineral N can influence crop residue decomposition when N for microbial activity is limiting (Heller *et al*., 2010).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site description

3.1.1 Location of study area

The field experiment was carried out at the Agricultural Research Station of the Kwame Nkrumah University of Science and Technology at Anwomaso, Kumasi-Ghana. Anwomaso is located within the semi-deciduous forest zone of Ghana. The site of the experiment lies at longitude 1° 31' 32.88" W and latitude 6° 41' 51.24" N.

3.1.2 Soil

The soil at the experimental site was identified as Kotei Series (Ghana classification) and Plinthic Vetic Lixisol (Profondic, Chromic) (IUSS working group WRB 2006). It is deep, moderately well drained soil on upper slope with average gradient of 5%. The topsoil (0-25 cm) layer of dark brown soil-sandy loam with moderate fine granular structure and contains many very fine roots. Underlying the A horizon is about 25-37 cm of brown sandy clay loam with a moderate medium subangular blocky structure.

3.1.3 Climate

The site experiences tropical monsoon climate with double maxima rainfall pattern separated by a short dry spell in August. The mean annual rainfall is 1400 mm. The major wet season is from March to uly with a peak in June while the minor wet season is from September to November with a maximum rainfall in October. The main dry season is from December to February. The mean relative humidity is 62 % and mean maximum and minimum temperatures of 30.6 °C and 21.1 °C, respectively.

3.2 Field Experimentation

3.2.1 Test crop

The test crop for the study was Obaatampa which matures within 110 days. Seeds were obtained from the Crop Research Institute (CRI), Fumesua, Kumasi. Germination test was carried out to determine the quality of seed and to decide the sowing rate. Germination was found to be 100%.

3.2.2 Duration of Study

The study was conducted in two growing seasons. The major season which started from April to August and the minor season which started from September to December. Plants were not irrigated during both seasons. However, the study site had received same treatment for 3 continuous years.

3.2.3 Experimental design

A Split plot design arranged in RCBD fashion with 3 replication to obtain a total of 48 plots (Figure 3.1). Tillage was the main plot factor and soil amendment was the sub plot factor. There were four levels of the main plot factor and four levels of the sub-plot factor giving a total 4 main plots or 16 sub-plot per block.

3.2.4 Experimental Treatments

3.2.4.1 Tillage practices

Four tillage practices were studied. They were;

No-Tillage (NT) as the control

Hoeing (H)

Plough Plant (PP) and

Ploughing and harrowing (PH)

3.2.4.2 Soil Amendments

Four different soil amendments were used in the study. These were:

a) No Amendment (N/A) B1 as the control

b) 60-40-40 NPK (15:15:15, NPK and Urea) (NPK) B2

c) 3 t/ha poultry manure (PM) B3

d) 30-20-20 NPK plus 1.5 t/ha poultry manure (HR) B4

3.2.5 Crop Husbandry practices

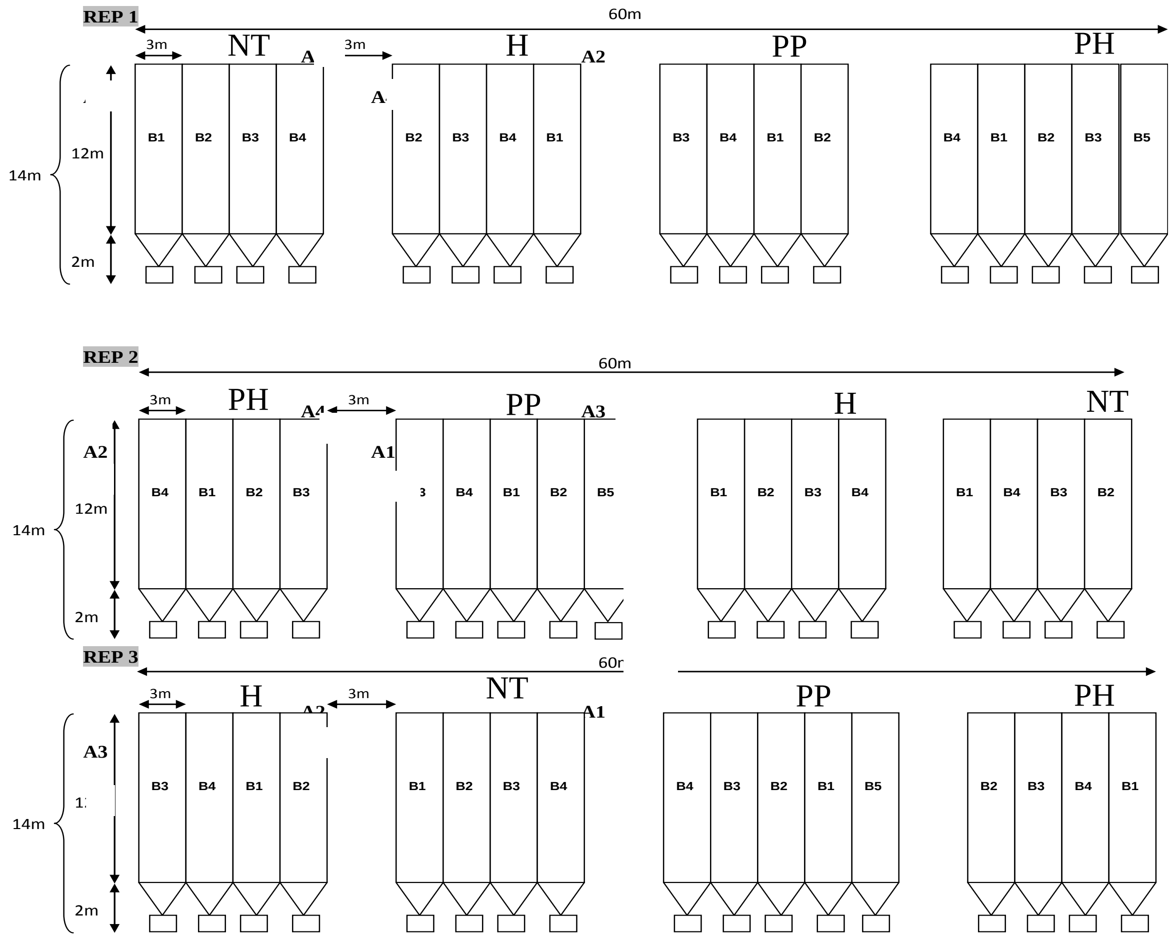
3.2.5.1 Land preparation

The land was slashed and cleared of vegetative cover and demarcated to various main plots and sub-plots with iron sheets. Plots were prepared according to the particular tillage practice to be used. NT plots were sprayed to kill weed, Hoe plots were weeded and prepared with a Hoe (Local tillage implement used mostly in Africa), and PP plots were ploughed with a mould board plough at 15-20 cm plough depth. For PH plots, ploughing was followed by harrowing (5 days after ploughing). Maize Stover (crop residue) from previous planting season were gathered from all plots and distributed on no-till plots.

3.2.5.2 Application of amendments

Poultry manure were broadcasted on the soil surface and incorporated into the soil except for the no-till main plots which were left on the soil surface. NPK was applied by ring application 2 weeks after planting (WAP) and Urea used as top dress 6WAP.

Experimental Lyout



Total land area = 60 m × 14 m × 3 = **2520 m^2**

Fig. 1. Runoff plot layout

Figure. 3.1 Field layout as represented on the field

NT = No-Tillage, H = Hoeing, PP = plough plant, PH = Plough and harrow, B1 = No amendment, B2 = 60-40-40 NPK (15:15:15, NPK and Urea) (NPK), B3 = 3 t/ha poultry manure (PM), B4 = 30-20-20 NPK plus 1.5 t/ha poultry manure (HR)

3.2.5.3 Sowing

The field was lined and pegged with rows arranged across slope. Three seeds per hill were planted and was later thinned to two stands per hill. Plant spacing was 80 x 40 cm. Total land area planted was 2560 m^2. Area per plot is 3 x 12 m, a total of 48 plots with 3 m spacing between main plots.

3.2.6 Agronomic Practices

3.2.6.1 Pest control

Weeds on NT plots were sprayed with weedicides to control weed growth and less disturb the soil. Weed control on Hoe plots were with the use of the hoe. Slashing of weeds was also done on both the PP and the PH treatments. Stem borers were controlled using systematic pesticide

3.2.7 Growth and yield parameters measured

3.2.7.1 height Plant

Five plants were randomly sampled and tagged in each sub plot. Plant height was measured with a meter rule from the base of the plant to the tip of the tallest leaf.

3.2.7.2 Maize yield

Maize cobs were harvested from the five middle roles within each subplot representing 27.28 m^2. Dehusking, drying and threshing followed the harvesting and at each step, weights were taken. After each season Crop residue were cut at the base and bundled on each subplot. The total biomass yield was then measured taking the weight of the bundled biomass. The final yield was expressed as tonne per hectare grain and biomass.

3.2.8 Field parameters

3.2.8.1 Soil temperature

Soil temperature was measured using a field thermometer. The thermometer was inserted into the soil to 5 cm and the digital temperature displayed was recorded when equilibrium was obtained. Weekly measurement was done on each sub plot for six weeks. The measurement started six (6) weeks after planting (6WAP) to coincide with emission measurements.

Unit for measurements was degree Celsius (^{o} C). Three (3) measurements (replications) were randomly taken to determine the average temperature.

3.2.8.2 Carbon emission

CO_2 emission was studied *in situ*. The soda lime absorption method by Keith and Wong (2006) was used to measure amount of CO_2 evolution from each subplot. This method was used because it appears to be most practicable method for field measurements and comparatively inexpensive and simple. Field carbon dioxide emission measurement was initiated from the last week of September to the first week of November, 2014. This measurement is based on the fact that soda lime traps CO_2 and its absorption is expressed in weight gain basis.

The reaction for the absorption is such that for every mole of CO_2 absorbed, a mole of water is produced and so it is always oven dried to evaporate the excess water. The reaction is as follows

$$2NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$$

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

3.2.8.2.1 Emission chamber

A white 15 litre bucket was used to construct the emission chamber. White buckets where used so that it could reflect a greater part of the light that it receives so as to limit the build-up of heat inside each chamber. The bucket had a diameter of 30 cm and a tight covering lid. The bottom of the bucket, 10 cm from below the lid was cut leaving the bucket with 10 cm as internal height (Figure 3.2).

A metallic template with the same shape and diameter of the bucket was used to cut the soil to enable easy insertion of the chambers (Plate 3.1). Three chambers were inserted in each sub plot. The chamber was to create a micro-climate of CO_2 evolution so as to measure and extrapolate for the whole experimental site.

The chambers were inserted two weeks after planting (2WAP). During this period, the soil should not in any way be disturbed and so the chamber was allowed to stay in the soil for four (4) weeks before emission study started. The chamber was left open until soda lime was placed inside the chamber. Fixing emission chamber can mechanically disturb the soil such that it might affect the diffusion coefficient and stimulate microbial activity. After collection of CO_2, values from the three chambers were summed and an average taken as the emission value per subplot per week.

Each chamber was pegged at two sides to make it firm. The lid of the bucket had a 2 cm depth around the edge which fits inside the rim of the bucket top to form a good seal (plate 3.2). A metallic stand of about 4 cm was inserted into each chamber to serve as a seat for the Petri dishes that contained soda lime (plate 3.3).

During the study, the chamber rim was coated with vacuum grease to ensure a tight seal between chamber and lid, and this was re-applied regularly.

All vegetation inside the chamber were clipped prior to soda lime installation to prevent CO_2 uptake or evolution. Four blank chambers (plate 3.4) were randomly placed on the field. These chambers are constructed same as the emission chambers only that, it was sealed at the top with a lid and at the bottom with another lid. They have similar volume as the emission chambers but not exposed to the soil. The blank measurements were made to account for the carbon dioxide absorbed by the soda lime during the experiment.

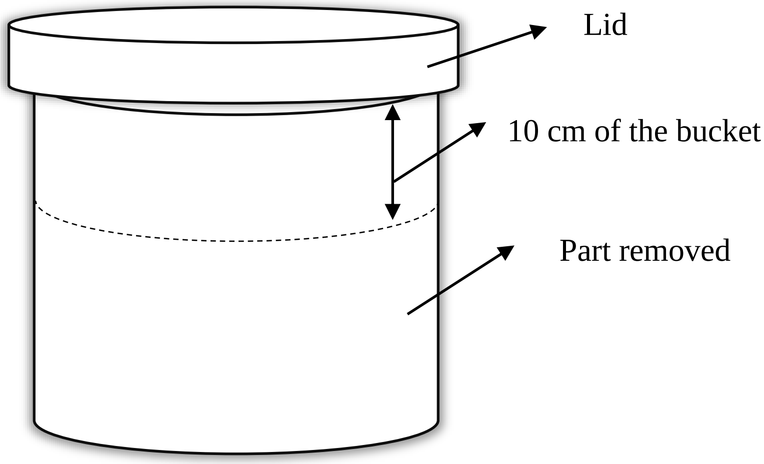


Figure 3.2. Diagram of the white bucket with demarcated part to be removed.

Plate 3.1 Chamber inserted in the soil before the emission study

Plate 3.2 Chamber covered during emission study

Plate 3.3. Blank Chamber

3.2.8.2.2 Soda lime

The soda lime is composed of NaOH and $Ca(OH)_2$ which are in the granular form. Petri dishes of 9.5 cm diameter were weighed and labelled. Fifty grams of the soda lime granules (mesh size of 2-4 mm) were measured into the Petri dishes. They were exposed and oven-dried in a fan forced oven at 105^{o}C for 14 hours (from 6pm to 8 am) (plate 3.4a). Soda lime in the Petri dishes were covered after the 14 hours and cooled in a desiccator. Petri dishes with soda lime were weighed to record the corrected dry weight of the soda lime (3.4b). Petri dishes with dried soda lime were sealed with electrical PVC insulation tape packed in an insulated box for field studies. At each chamber in the field, petri dishes were untapped and water (8 mls for 50 g) was put on the soda lime using a fine spray that evenly wets all the granules. Some moisture is required with the exposed soda lime because the reaction between hydroxide and CO2 requires the presence of water. The exposed soda lime in the Petri dishes were placed on the metallic stand inserted into the ground within the chambers and lids closed. Vacuum grease was applied before the lid is placed to make the seal air-tight. The soda lime was exposed for 24 hours. After the 24-hour period, the lid was removed, Petri dishes covered and sealed with PVC insulation tape, packed into the insulated box to be transported to the laboratory. At the laboratory, Petri dishes with the soda lime were oven dried for 14 hours to evaporate the moisture produced during the reaction and the 8 ml water applied.

The weight of the oven-dried Petri dishes with the Soda lime from the field was recorded and the weight difference with the previous weight before the field absorption was noted and used to calculate CO_2 evolution. Petri dishes with 50 g soda lime that went through the same process of drying and weighing, were placed in blank chambers and left for 24 h in the field to simulate conditions of the incubating chambers. Blank measurements are to account for CO_2 absorbed by soda lime during the experimental procedure.

Plate 3.4a soda lime in Petri dishes in a fan dishes

Plate 3.4b Cooling of Petri content forced oven in desiccator

The weights recorded include;

Petri dish, Petri dish and soda lime, Petri dish and dried soda lime, Petri dish and exposed dried soda lime. CO_2 evolution was calculated as follows:

$$\text{soil } CO_2 \text{ efflux } \left(\text{g Cm}^{-2}\text{day}^{-1}\right) = \left\{\frac{\left[\left(W_1(\text{g}) - \text{Wb (g)}\right) \times 1.69\right]}{\text{A (m}^2)}\right\} \times \left[\frac{24 \text{ (h)}}{\text{D (h)}}\right] \times \left[\frac{12}{44}\right]$$

Where: W_1 = Sample weight gain Wb = mean blank weight gain

A = chamber area D = duration of exposure

1.69 = correction factor for water formed during the chemical absorption of soda lime

12 = molecular mass of carbon 44 = molecular mass of carbon dioxide

3.2.8.3 Soil sampling

Soils were sampled based on the parameter to be measured. Core samplers were used to sample for bulk density and moisture content. Soil auger was used to sample for soil chemical and physical analysis in the laboratory.

3.2.8.3.1 Initial soil sampling

Soil samples were taken at 0-15cm and 15-30 cm depth along the diagonals of the experimental plots. Samples were taken for each depth class and bulked according to main plot effect to get four composite samples to represent each of the main plot effects. Samples were air dried and passed through the 2 mm sieve and used to determine the initial physical and chemical properties of the soil.

3.2.8.3.2 Sampling during the study

Three soil samples were taken per plot and bulk to represent that plot. The sampling was done randomly per plot. Sampling was done with test auger and core samplers. Soils were sampled each week for six weeks for moisture determination. In all eight (8) sampling were done during the growing cycle of the test crop.

3.3 Laboratory analysis

All physical and chemical analysis was carried out in the Soil Science Laboratory of the Department of Crop and Soil Sciences, KNUST, Kumasi, Ghana.

3.3.1 Soil bulk density

Core samplers of 3.5 cm radius and 15 cm length was used to sample soil from 0-15 cm and 15-30 cm depths. Three sub samples per each subplot was sampled and bagged into a labelled black polythene bag. Soil samples were brought to the laboratory and soils were emptied into pre-weighed aluminium pans and oven dried for 24 hours at 105 ^{o}C in a fan forced oven. Soil dry weight after oven drying was measured and dry bulk density was calculated using the mass per unit volume ratio as illustrated below.

$$\rho b\ \left(\frac{g}{cm^3}\right) = \frac{m_s}{Vt}$$

Where: ρb (g/cm^3) = bulk density

m_s (g) = soil dry weight

Vt (cm^3) = total volume of soil, calculated as $\pi r^2 h$ (r = radius of core sampler, h = height of core sampler)

3.3.2 Soil moisture

Soil moisture per subplot was taken during the minor season of the experiment. It was carried out weekly for six (6) continuous weeks (starting at 6 WAP). Three sub samples were collected, bulked into a composite sample per subplot and dried at 105^{o}C for 24 hours. Gravimetric water content was calculated using the formula:

$$Gw = \frac{\text{grams of water}}{\text{grams of dry soil}}$$

$$\theta_g = \frac{W_2 - W_3}{(W_3 - W_1)}\ (^g/_g)$$

Where: Gw = gravimetric water content W$_1$ = weight of the empty container

W_2 = weight of most soil + container W_3 = Weight of dried soil + container

g/g = unit of measurement.

Gravimetric water content was then converted to volumetric water content by the following

$\theta_v = \theta_g \times \rho_b$ ($^v/_v$)

θ_v = volumetric water content

ρ_b = bulk density

v/v = unit of measurement

θ_g = gravimetric water content

3.3.3 Soil total and air-filled porosity

Total Soil porosity was calculated using soil bulk density measured per sub plot and soil particle density (assumed as 2.65 g/cm^3) from the formula below:

$$f = 1 - \frac{\rho b}{\rho s}$$

Air-filled porosity was extrapolated using the total porosity and volumetric water content.

3.3.4 Soil fractionation (Six *et al*., 1998; 2000)

The method allows differentiation of soil aggregates classes within the soil. Sampling was done to determine the effect of the applied treatments after 3 years of continuous application. Fresh and undisturbed soil samples from each plot were passed through 8 mm sieve to homogenize the soil particles. Soil particles that could not pass through the sieve were gently broken with the hand. Plant debris and stones were removed. Samples were then air dried.

A white bowl of about 30 cm diameter and 8 cm deep was filled with distilled water such that the level of water was about 1 cm above the 2 mm sieve mesh. Eighty grams of air-dried soil sample was weighed and spread evenly on the 2 mm (2000 µm) mesh and allowed to sit for 5 minutes to allow for the process of slaking to take place. After the slaking process, the soil was sieved for 2 minutes by gently moving the sieve up and down 50 times with a slight angle to ensure that water and small particles passed through the sieve.

After the wet sieving, the sides of the sieve was rinsed using wash bottle to wash the fine particles through the sieve. The soil particles that remained on the 2 mm sieve mesh was then transferred into a pre-weighed aluminium pan. Backwashing of the sieve mesh was done to ensure all particles entered the aluminium pan. Floating litter was then decanted into a waste bucket after the back washing. The macro aggregates (soil particles that was left on the 2 mm sieve mesh) was put into a fan forced oven at 60^{o}C.

The water and soil particles that went through the 2 mm sieve was poured unto a 0.25 mm (250μm) sieve mesh. The 0.25 mm sieve was raised and water on the sieve allowed to drain. The sieving procedure was repeated, moving the sieve up and down 50 times. After the sieving, the sides as well as the bottom of the 0.25 mm sieve was washed to bring small soil particles into suspension. The particles that stayed on the 0.25 mm sieve is termed small micro aggregates. This was washed into another pre-weighed and labelled drying pan. The soil particles that stayed on the 0.25 mm sieve are the small macro aggregates.

Water that remained in the white bowl and the soil particles that passed through the 0.25 mm sieve was poured unto the 0.053 mm (53 μm) sieve mesh. The sieve was raised and the excess water above the sieve mesh was allowed to drain. The sieving procedure was repeated moving the sieve up and down 50 times and the bottom and sides of the sieve were washed and then backwashed. The particles on the 0.053 mm sieve mesh was then transferred into another pre-weighed and labelled drying pan. This soil fraction is called micro aggregates.

The white bowl was then emptied into yet another pre-weighed drying pan. The latter fraction is the silt and clay fraction. The fractions were then put into a fan forced oven at 60^{o}C till it was evenly dried. The recovery of size separates after the fractionation ranged from 91 to 99% of the initial soil mass.

3.3.5 Aggregate stability

Aggregate stability determination was done using Pieri (1991) method of critical level of SOM content needed to maintain a favourable level of soil structure where soil organic matter, silt and clay content to estimate soil stability in terms of the carbon content within the soil. It was estimated as follows;

$$St = \frac{(SOM)\%}{(clay + silt)\%} \times 100$$

Where: St = stability SOM = soil organic matter

Pieri (1991) proposed a scale based on soils from West Africa, presented below:

St = < 5%, Loss of soil structure and high susceptibility to erosion

St = 5%-7%, unstable structure and risk of soil degradation

St = > 9%, stable soil structure.

3.3.6 Particle size analysis

The hydrometer method was used. Fifty one grams of air-dried soil sample (<2 mm) was measured into a beaker. 50 ml calgon (prepared with sodium hexametaphosphate and sodium carbonate) followed by 100 ml deionized water was then added to the soil sample. The suspension was vigorously stirred for a minute with a stirring rod and allowed for to stand for 30 minutes. After which were then transferred into a mixer and mixed at medium speed for 15 minutes.

The suspension was then transferred into 1000 ml sedimentation cylinder and made up to the 1000 ml mark with deionized water. The suspension in the sedimentation cylinder was plunged using a plunger to thoroughly mix the suspension. The hydrometer was slowly slid into the suspension and the first hydrometer reading (H1) was taken after 40 seconds. Temperature (T1) in degree Fahrenheit (^{O}F) was measured after the first hydrometer reading. The plunging of the suspension, hydrometer readings and temperature readings were repeated. The suspension was then allowed to stand undisturbed for three (3) hours at the end of which the second hydrometer reading (H2) and temperature (T2) were taken. Particle size distribution is calculated from the formula shown in the matrix below:

H_1 A	T_2	B	C	% sand	D	E	F	% clay	G	% silt
H_1 H_1	T_1 T_1	T_1 – 68 × 0.2	A + B – 2	100 – (2 × C)	H_2	T_1 – 68 × 0.2	D - 2	F + E × 2	Sand + Clay	100 - G

Where: H_1 = average of first two hydrometer readings

T_1 = average of first two temperature readings (^{o}F)

H_2= second temperature reading

T_2 = second temperature reading (^{o}F)

3.3.7 Soil pH

Soil pH was determined using the electrometric method as described by Page *et al*. (1982). Soil to water ratio used was 1:1. Ten grams of air-dried soil sample were mixed with 10 ml distilled water. The suspension was thoroughly stirred and allowed to stand for 30 minutes. The pH of the samples were read with a calibrated the pH meter.

3.3.8 Total nitrogen

Total nitrogen was determined using the Kjeldahl (1984) method of digestion and distillation. Ten grams of air-dried soil was digested in a 500 ml round bottom flask over source of heat after 100, 10 and 1 parts of Sodium sulphate, Copper sulphate and selenium were respectively added. The Digest was cooled and decanted and made up to 100 ml. An aliquot of the digest was distilled with 20 ml NaOH in a kjehdahl distillation apparatus. The distillate was collected over 10 ml of 4 % Boric acid and 3 drops of mixed indicator in a beaker. The distillate was titrated with 0.1 N HCl to a colour change of blue to pink. Total Nitrogen was then calculated using the formula:

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

Where:

A = volume of standard HCl used in the sample titration N = Normality of standard HCl

B = volume of standard HCl used in the blank titration W = weight of air dried soil

1.4 = (14 (atomic mass of Nitrogen) x 100) / 1000Organic carbon

.3.9 Organic Carbon3

Organic Carbon was determined using modified Walkley and Black method (1934). Organic carbon was extracted from 2 g of the air dried soil sample with 10 ml of 1.0

N potassium dichromate ($K_2Cr_2O_7$) and 20 ml 98% sulphuric acid. The extraction reaction was stopped with 200 ml distilled after 30 minutes and 10 ml orthophosphoric acid and 2 ml diphenylamine indicator were added to the suspension. Suspension was titrated with 0.5 N ferrous sulphate solution to change the colour from dark blue to green. Blank samples were added. Percentage carbon was calculated from the steps below

$$\%C = \frac{M \times (V_{bl} - V_s) \times 0.003 \times 1.33 \times 100}{g}$$

Where: M =Molarity of $FeSO_4$ V_{bl} = ml $FeSO_4$ of blank titration

V_s = ml $FeSO_4$ of soil sample titration g = mass of soil taken in gram

0.003 = milli-equivalent weight of C in grams (12/4000)

1.33 = correction factor used to convert the Wet combustion C value to the true C value

Soil organic carbon stocks were calculated using Lee *et al*. (2009) method of carbon stocks estimation as follows;

$SOC_{(t/ha)} = C_{(conc)} \times M_i$

Where: $SOC_{(t/ha)}$ = soil organic carbon stocks in tons/hectare

$C_{(conc)}$ = % organic carbon in the soil divided by 100

M_i = Mass of soil in a hectare which is calculated as $M_i = BD \times D \times 10^4$

Where; BD = bulk density (Mg/m^3) D = soil thickness (m)

10^4 = a unit of conversion factor (m^2/ha)

3.3.10 Available phosphorus

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

Calculation:

$$P\left(\frac{mg}{kg}soil\right)=\frac{(a\text{-}b)\times 35\times 15}{w}$$

Where: a = mg/L P in sample extract b = mg/l P in blank

35 = ml extracting solution 15 = ml final sample solution

w = sample weight in gram

3.3.11 Exchangeable cations

Soil extract was prepared by weighing 10 g of air dried and sieved (<2 mm) soil samples into extraction bottles after which 100 ml 1.0 N buffered (pH = 7) ammonium acetate solution was added and shaken on a mechanical shaker for 2 hours at 300 rpm. Suspension was then filtered through No. 42 Whatman filter paper. Aliquots were then taken to determine exchangeable cations.

3.3.11.1 Determination of calcium and Magnesium

EDTA (Versanate Ethlyene-Dymine tetra acetic acid) method was used. Calcium and Magnesium was measured by we

3.3.12 Exchangeable acidity

Two grams air-dried soil sample was weighed and put into a folded filter paper in a funnel and placed on a 100 ml conical flask. Fifty millilitres 1.0 N potassium chloride

(KCl) solution was gently poured on the weighed soil sample to leach the soil and the leachate was collected in the conical flask. 5 drops of phenolphthalein indicator was added and the suspension titrated with 0.05 N NaOH to measure exchangeable acidity (Al^{3+} and H^{+}). The colour change was from pink to colourless. The volume of NaOH used was recorded as (V_1).

4 ml of 3 N sodium fluoride (NaF) was added to the titrated suspension and the suspension was then titrated with 0.05 N HCl to measure exchangeable aluminium (Al^{3+}). Volume of HCl used was recorded as (V_2). Exchangeable acidity and aluminium in meg / 100 g was respectively calculated using the formula below;

$$\text{Exchangeable acidity (meq/100 g)} = \frac{V_1 \times 0.05 \times 100}{w}$$

Where: V = Titre volume of NaOH used (ml) Normality of NaOH = 0.05 N

W = weight of soil sample used 3 (g)

$$\text{Exchangeable aluminium (meq/100 g)} = \frac{V_2 \times 0.05 \times 100}{w}$$

Where: V = Titre volume of HCl used (ml) Normality of HCl = 0.05 N

W = weight of soil sample used (3 g)

3.3.13 Microbial biomass carbon (Vance *et al*., 1987; Anderson and Ingram, 1993)

Fresh soil samples were used three sub samples of 15 g each were weighed. One was oven-dried to determine the moisture correction factor, the second sample was fumigated and the other was not fumigated but incubated. The soil samples to be fumigated (CF) were weighed into 50 ml glass beakers and placed around 25 ml washed chloroform in desiccator. Another set of samples were arranged into another desiccator without chloroform solution (Non-fumigated (NCF)). Using a vacuum pump, pressure was created in the fumigated samples such that the chloroform boiled rapidly. The desiccator outlet where the vacuum was applied was then closed and samples were incubated for 72 hours in a dark room. After this, the fumes in the fumigated chamber was evacuated. Non fumigated samples were also incubated for 72 hours. Both sets of samples were transferred into shaking bottles, extracted with 50 ml 0.5M potassium sulphate (K_2SO_4) and then filtered with a whatman No. 42 filter paper.

Ten millilitres of the filtrate was pipetted into digestion tube. Five millilitres potassium dichromate and 7.5 ml 98% sulphuric acid were added and digested in a block digester at 150^{o}C temperature for 30 min. the digested samples were allowed to cool and transferred into 100 ml conical flask. The digests were titrated with 0.2M ferrous ammonium solution after 0.3 ml phenantroline monohydrate-ferrous sulphate was added. The colour change was from green to brown. Microbial biomass carbon (MBC) was calculated by the formula

$$MBC = (CF - NCF) \times 2.64$$

Where: CF = carbon estimated from the fumigated samples

NCF = Carbon estimated from the non-fumigated samples

2.64 is the correction factor for MBC determined by fumigation

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Initial soil characterization

4.1.1 Initial chemical and physical properties of study site

Soil at the study area was and characterized to ascertain their initial chemical and physical properties as presented in Table 4.1a and 4.1b below. Based on the characterization, the soil was classified as Plinthic Vetic Lixisols. The soil was strongly acidic (pH of 4.85 and 4.78) in the 0 – 15 cm and 15 – 30 cm soil depths respectively. The low pH could be due to the old and highly weathered and highly leached soil at the study site. Initial organic carbon and carbon stocks at both soil depths were generally low (1.2%; 2.376 t/ha and 1.11 %; 1.98 t/ha for 0-15 and 15-30 cm respectively).

Table 4.1a. Initial chemical properties of soil at the study area.

Soil Parameter	Soil Depth	
	0-15 cm	15-30 cm
pH (1:2.5)	4.85	4.78
Organic Carbon (%)	1.20	1.11
Carbon stocks (t C/ha)	23.76	21.98
Total N (%)	0.12	0.10
Available P (mg/kg)	25.60	20.60
Exchangeable Ca ($cmol_{(+)}$/kg)	3.75	3.10
Exchangeable Mg ($cmol_{(+)}$/kg)	1.30	1.33
Exchangeable Na ($cmol_{(+)}$/kg)	0.13	0.12
Exchangeable K ($cmol_{(+)}$/kg)	0.31	0.22
Exchangeable Acidity (Al + H)	0.95	0.71
ECEC ($cmol_{(+)}$/kg)	6.43	5.45

Similarly, the initial nitrogen content of the study site was low (0.12% and 0.1 %) within both soil depths. Available phosphorus was 25.6 mg/kg and 20.6 mg/kg for the respective soil depths. Exchangeable cations progressed from $Na^{+} < K^{+} < Mg^{2+} < Ca^{2+}$ both soil depths (Table 4.1a). The low carbon contents of the soils could account for the low aggregate stability of the soil (Table 4.1b) and probably affected its nutrient retention ability. This observations substantiates the report by Govaerts *et al.* (2008) that organic carbon is one of the most important determinants of soil health and it is linked to increased nutrient retention, eventuating in sustainable agricultural production.

The initial structural parameters of soil at the study area was assessed and they are presented in Table 4.1b.

Table 4.1b. Initial physical properties of soil at the study area.

Soil physical Parameters	**Bulk density (Mg/m^3)**	**Total porosity (%)**	**Aggregate stability**	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Textural class**
	1.32	50.19	5.29	77.32	6.84	15.84	Sandy loam

The soil had low bulk density (1.32 Mg/m^3) and good porosity (50.19 %). Aggregate stability was susceptible to soil structural degradation (Pieri, 1991). The textural class of the soil at the study site was sandy loam.

4.2 Final physico – chemical properties of the soil

4.2.1 Chemical properties

Soil at the study area were analysed and characterized to ascertain their final chemical properties after field work as presented in Table 4.2 and 4.3 below.

Carbon stocks determined from the 0-15 and 15-30 cm depth under the different tillage practices increased in the order of PH < PP < H < NT and PH < H < NT < PP respectively. Soil organic carbon stocks reduced with depth from the soil surface (Table 4.2) on NT and H plots, but a reverse was recorded on plough plant and plough harrow plots and this can be ascribed to the soil turnover during the tillage practice (Sainju, 2006).

Table 4.2. Effect of tillage practices soil amendment on soil chemical properties

Tillage	**Carbon stocks (t/ha) Soil depth (cm)**	
	0-15 cm	**0-15 cm**
NT	48.9	38.2
H	41.8	39.1
PP	38.1	42.1
PH	17.7	34.3
Lsd (0.05)	8.18	NS
CV (%)	26.8	24
Soil amendment		
PM	36.9	37.1
NPK	36.9	38.6
HR	36.9	38.8
NA	35.8	39.2
Lsd (0.05)	N/S	NS
CV (%)	26.8	24

NT = no tillage; H = hoe tillage; PP = plough plant tillage; PH = plough harrow tillage; N/S = no significance, CV= coefficient of variation

Soil amendment increased carbon stock within the subsoil than the topsoil though there was no significant difference ($p > 0.05$) between the amendments applied at both depths.

No amendment plots recorded the highest and lowest carbon stocks for the subsoil (15-30 cm) and topsoil (0-15 cm) respectively. The inability of poultry manure alone or its combination with chemical fertilizer to significantly influence soil organic carbon contents was probably due to its initial carbon content (Table. 4.2).Within a three year period, the initial carbon stocks measured increased across the tillage and soil amendment applied (Tables 4.1a, 4.2 and 4.2) except for PH effect at the topsoil.

No-till practices recorded the highest carbon stock (25.76 t/ha) about 77.19% more in the top soil compared to the initial whereas the PP practices stored the highest carbon (18.34 t/ha) in the subsoil (15-30 cm), accruing 105.8% more carbon than the initial subsoil content. The PH plots recorded lower carbon stock at the top soil (17.7 t/ha) than was initially measured (23.76 t/ha).

4.2.2 Effect of tillage and soil amendment on soil structural parameters

Final physical properties of the soil was assessed to ascertain the effect of the various treatment and the results are presented in Table 4.3 and 4.4 below.

From Table 4.3, Bulk density was significantly influenced by tillage practices ($p < 0.05$). The highest was recorded on PH plots and the least on NT plots. Hoe tillage, plough plant and plough harrow were significantly similar but significantly different from NT plot. Carbon stock in the NT plots were significantly higher ($p < 0.05$) than in the PP and PH plots (Table 4.2) at the topsoil (0 – 15 cm) and could explains the low bulk density of the NT plot since organic carbon content is inversely related to bulk density in mineral soils (Sarkar *et al*., 2003).

Table 4.3. Effect of tillage practices on physical properties of the soil.

Tillage	Bulk density (Mg/m^3)	Porosity (%)	Air-filled porosity (%)	Aggregate stability
NT	1.1764	55.15	43.76	12.69
H	1.2435	53.78	43.52	10.68
PP	1.2559	52.65	43.75	9.39
PH	1.2661	51.73	41.39	4.04
Lsd (0.05)	0.05164	1.030	1.072	1.814
CV (%)	5.0	2.3	3.0	23.6

NT = no tillage; H = hoe tillage; PP = plough plant tillage; PH = plough harrow tillage; N/S = no significance, CV= coefficient of variation

Soil compaction by the tractor tires used to plough and harrow could also account for the relatively higher bulk density under PH plots. Conventional tillage (plough plant and plough harrow tillage) initially decreases bulk density but it increases subsequently with trips of the tractor on the soil surface, erratic rainfall events, and other pedoturbation activities (USDA-NRCS, 2008). Ussiri and Lal (2009) also observed lower bulk density with NT plots than conventionally tilled plots at the 0 – 15 cm soil depth. Salam *et al*. (2013), however, found significantly lower bulk density for deep tillage than no tillage plots.

This was because deep ploughing was coupled with higher biomass incorporation leading to lower bulk density under conventional tillage than NT. Total porosity ranged from 51.73% on PH plots to 55.15% on NT plots. There was significant differences between treatment means, except between PP and PH plots ($p < 0.05$). Air-filled porosity was significantly lower ($p < 0.05$) in PH plots than NT, H and PP which were statistically similar. Higher total porosity and air-filled porosity recorded on the NT plots could be ascribed to their negative relationship with bulk density, hence higher in the NT than conventional tillage plots (Table 4.3) (Salam *et al*., 2013).

Tillage practices had significant effect ($p < 0.05$) on aggregates stability (Table 4.3). Plough and Harrow, by Pieri (1991) scale, degraded the soil structure and made the soil more susceptible to erosion. No till, H and PP tillage maintained soil structure, but, NT maintained soil structure better than H and PP tillage practices. Plough plant and hoed plots were statistically similar in their effect on structural stability.

Conventional tillage practices breakup soil aggregates, pulverize the soil and destroy soil structure. Bronick and Lal (2005), explained that no tillage connotes no disturbance of soil aggregates and hence relatively more stable aggregates were under no tillage than the other tillage practices. Soil porosity was the only property that was significantly influenced by soil amendment (Table 4.4). The combination of half rates of chemical fertilizer and poultry manure produced the highest total porosity. Poultry manure reduced soil porosity relative to the combined organic and inorganic soil amendment. Notwithstanding significant similarity with soil amendment effect on Ea, ρ_b and aggregate stability, HR application resulted in the highest Ea and lowest ρ_b. NPK amendment also recorded the highest stability value.

Table 4.4. Effect of soil amendment on soil physical properties

Amendment	Bulk density (Mg/m^3)	Porosity (%)	Air-filled porosity (%)	Aggregate stability
PM	1.2532	52.67	43.19	9.14
NPK	1.2286	53.50	43.13	9.82
HR	1.2183	54.17	43.82	8.78
NA	1.2419	52.97	42.29	9.05
Lsd (0.05)	N/S	1.030	N/S	N/S
CV (%)	5.0	2.3	3.0	23.6

PM = poultry manure; HR = half rates of PM and NPK; NA = no amendment; N/S = no significance, CV= coefficient of variation

Integrated application of poultry manure and NPK (HR) provides more organic matter (organic carbon), increases nitrogen and CEC contents of the soil which in consequence improves water holding capacity and reduces soil bulk density (Hati *et al*., 2006) and this report was affirmed by results from the study (Table 4.4). Since bulk density is inversely proportional to soil porosity (Table 4.5), the half rates of poultry manure and NPK (HR) effect also increased total porosity in the treated plots.

The soil amendments had no significant effect on structural stability probably due to the overshadowing effect of tillage practices and also that poultry manure and NPK takes a longer time to effect the soil's structural stability

Table 4.5. Coefficient of correlation between bulk density, soil organic carbon content (0 – 15 cm), soil porosity and air-filled porosity

Independent	Dependent	r^2
Bulk density	Total porosity	-0.823**
Bulk density	Air-filled porosity	-0.6912**
Total porosity	Air-filled porosity	0.8571**

** = significant at 1%; r^2 = coefficient of determination

High bulk density usually connotes lower pore spaces and vice versa, hence the negative relationship between bulk density and porosity parameters. This explains NT plots recording lower bulk density and relatively higher total porosity and air-filled porosity.

4.3 Effect of Tillage and soil amendment on volumetric water content and soil temperature.

Weekly soil moisture content and soil temperature determined in the various plots are presented in the Table 4.6 and Figures 4.1 to 4.4 below.

Weekly water contents differed significantly ($P < 0.05$) among the various plot (NT, H, PP and PH) (Figure 4.1). Average moisture content was higher ($p < 0.05$) on PH plots (0.1117 cm^3/cm^3) and least on PP plots (0.0958 cm^3/cm^3). However, the NT plots moisture contents in weeks 1 and 3 were higher than those of the PP and PH plots (Figure 4.1). This could be ascribed to the relatively higher porosity on the NT plots than the other plots (Table 4.2) that received heavy tillage operations.

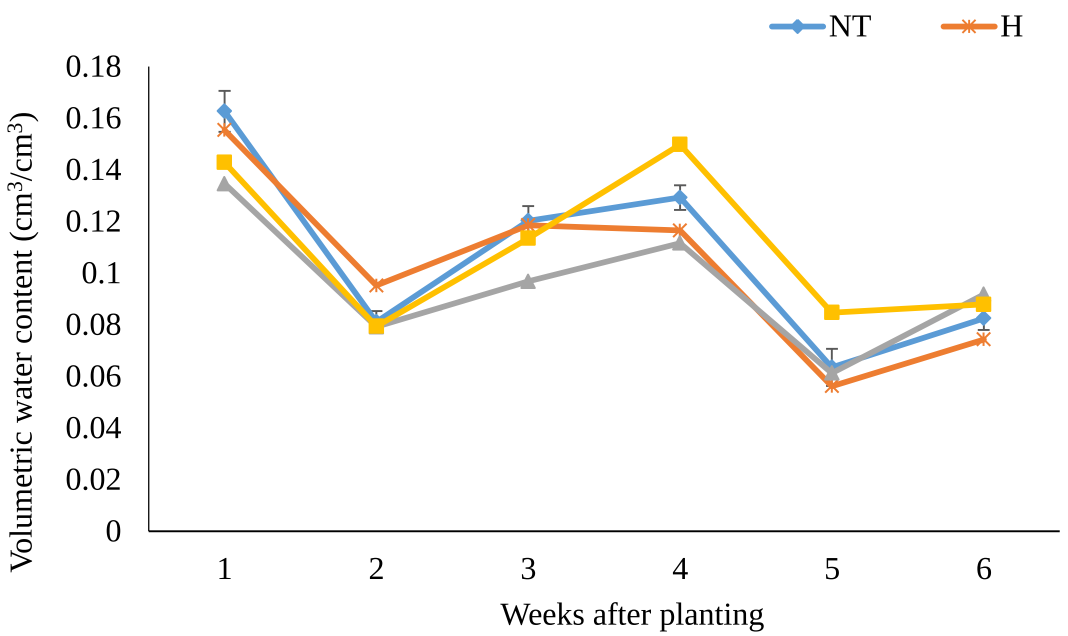


Figure 4.1. Volumetric water content (cm3/ cm3) measured for six weeks.

Averagely, PH plots recorded higher moisture contents than the other tilled practices employed (Table 4.6). This is probably because, ploughing and harrowing pulverizes the soil and create macropores that are able to collect more water after every rainfall event. However, NT mostly retain more moisture due to the mesopores which is higher under NT than under conventional tillage (Taylor *et al*., 2012). Average soil moisture was highest under NA plots (0.1108 cm^3/ cm^3) and least under NPK amended plots (0.0983 cm^3/ cm^3) (Table 4.6).

Table 4.6. Average weekly soil temperature and volumetric moisture content

Tillage	**Temp (^oC)**	**Moisture (θ_v)(cm^3/cm^3)**
NT	30.03	0.1067
H	31.52	0.1033
PP	30.93	0.0958
PH	30.27	0.1117
Lsd (0.05)	1.081	0.00799
CV (%)	4.2	9.2
Soil amendment		
PM	30.53	0.1033
NPK	30.31	0.0983
HR	30.54	0.105
NA	31.37	0.1108
Lsd (0.05)	N/S	0.00799
CV (%)	4.2	9.2

N/S = no significance, NT = no tillage, H = hoe tillage, PP = plough plant tillage, PH = Plough – harrow tillage, PM= poultry manure, NPK = NPK 15:15:15 + Urea; HR = NPK + PM; NA = no amendment

From Figure 4.2, soil amendments had significant influence ($p < 0.05$) on moisture content in the treated plots for weeks 4 and 6. Effect of soil amendment also followed similar rise and fall trend from week one to week six. No amendment plots recorded the highest moisture contents at week 4 and week 6. This occurred probably because the plants had low vigour to absorb water because the plants were stunted due to low nutrients.

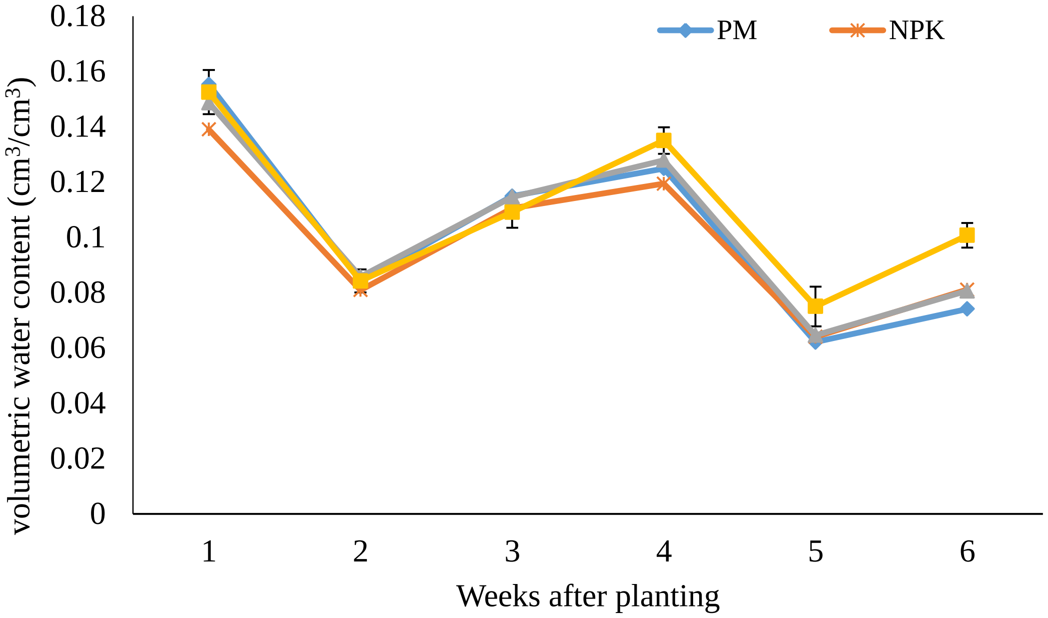


Figure 4.2. Soil moisture content per week as affected by soil amendments

Tillage significantly influenced ($p < 0.05$) soil temperature per the weekly data (Figure. 4.3). Soil temperature values were consistent throughout the measurement periods on the various plots (Figure 4.3). Temperatures were generally high at week one, low at week six and fairly constant from week two to five. Highest soil temperature, for all the six weeks of measurement, were recorded under plots whereas the lowest temperature were recorded under NT plots from weeks 1 to 6 except for week 5 which recorded lowest soil temperature under PH plots (Figure 4.3). Average soil temperature was highest under H plots (31.52 ^{o}C), then PP plots (30.93 ^{o}C), PH plots (30.27 ^{o}C) and then lowest under NT plots (30.03 ^{o}C). Higher soil temperature in conventional plots than NT plots were probably as a result of modified thermal conductivity by the tillage practices applied (Silva – Olaya *et al.*, 2013). Low soil temperature for NT plots could also be linked to the crop residues left on the NT plots, since crop residues are reported to have high solar reflection ability and lower thermal conductivity (Fabrizzi *et al*., 2005).

In contrast, Hillel (1998); Salem (2015) observed higher soil temperature under NT plots than under conventional tillage due to decomposition of organic matter from continuous application of organic materials on NT plots.

Soil temperature values were similar for the different weeks except for week 5 (Figure 4.4). No amendment plots recorded the highest average soil temperature (31.37 ^{o}C) whereas the lowest average temperature (30.31 ^{o}C) was recorded under NPK amended plots. It could be inferred from Figure. 4.4 that the application of the various soil amendment combinations stepped down the soil thermal conductivity and lowered its ability to generate more temperature relative to NA plots (Silva – Olaya *et al*., 2013).

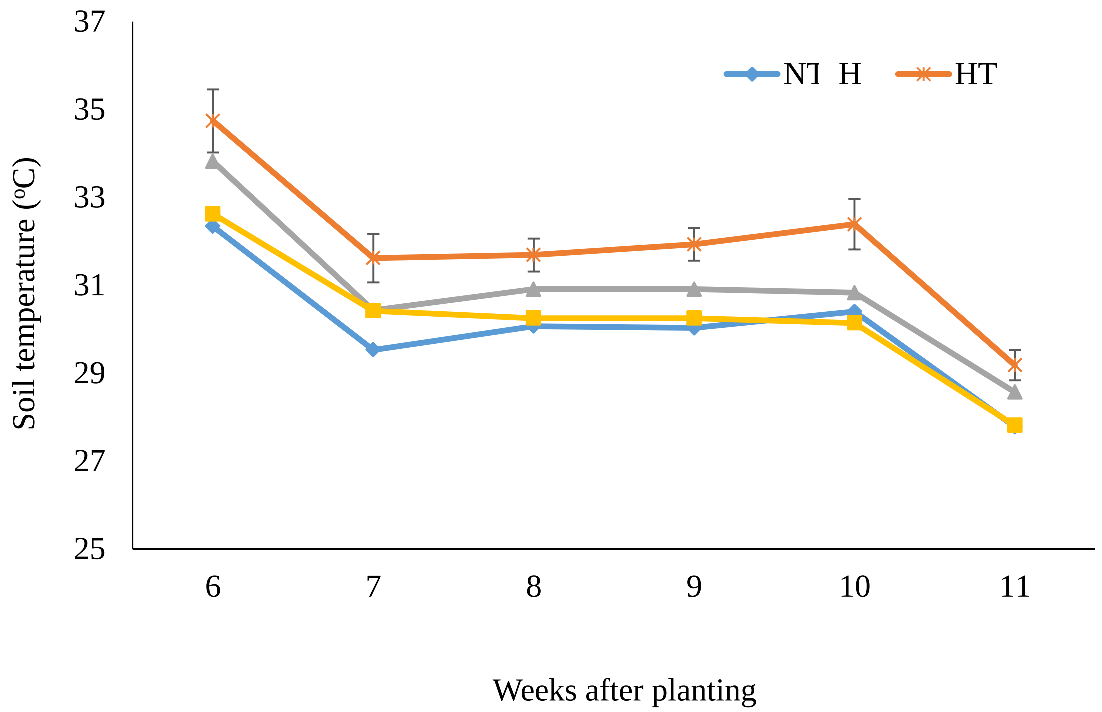


Figure. 4.3. Soil temperature (oC) per week as affected by tillage practices

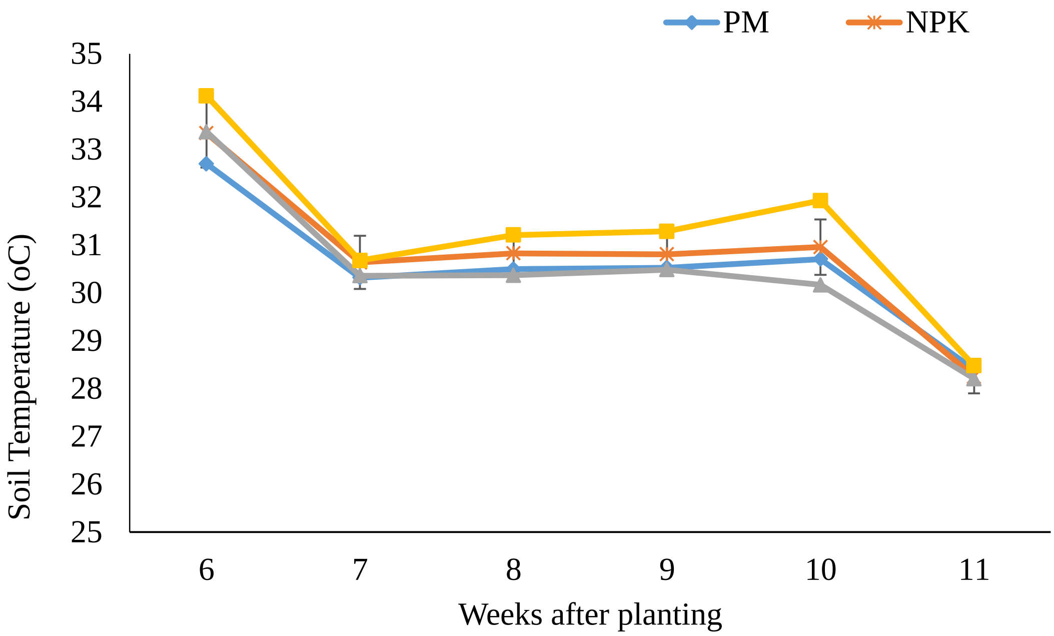


Figure. 4.4. Soil temperature per week as affected by soil amendment.

4.4 Tillage and soil amendment effect on soil fractionation

Soil fractionation by wet sieving method separated the various soil samples taken from tilled and no till plots into four main fractions. Table 4.7 presents the effect of the various tillage practices and soil amendments on the various soil separates after 3 years of continuous application. Figure 4.5 and 4.6 also show the interactive effect of the two treatments applied on soil aggregate fractionation.

Soil fractionation carried out in the study was to determine the effect of the various tillage practices on the separation of soil particles into individual constituent upon the administration of that tillage practice. All the aggregate fractions were more abundant in the 15 – 30 cm depth samples than the 0 – 15 cm soil depth except for the LM fraction which recorded greater values in the 0 – 15 cm depth than the 15 – 30 cm depth (Table 4.8). This trend was observed for both tillage and soil amendment effects on soil aggregate fractionation.

Bronick and Lal, (2005), observed decreasing aggregation moving down the soil depth. Also, tillage and soil amendment effects caused more variability within the top soil (0-15 cm) (CV = 21.3-31.9%) than within the subsoil (15-30 cm) (CV = 7 – 15%) (Table 4.8)

Table 4.7. Effects of Tillage and soil amendments on proportions of soil aggregate fractions

Tillage	**Soil fractions**							
	LM (> 2000 µm)		**SM (250-2000 µm)**		**M (53-250 µm)**		**S+C (< 53 µm)**	
	Depth class (cm)							
	0 - 15	**15 - 30**	**0 - 15**	**15 - 30**	**0 - 15**	**15 - 30**	**0 – 15**	**15 - 30**
	%							
NT	44.30	26.08	35.80	49.67	12.53	17.92	3.61	5.59
H	47.70	35.78	33.30	42.67	12.85	15.68	4.22	5.06
PP	37.60	32.84	36.40	40.14	17.18	18.95	6.23	7.26
PH	39.10	33.92	37.00	41.23	17.78	17.93	4.97	6.26
Lsd (0.05)	N/S	2.39	N/S	2.54	3.59	1.31	1.27	0.75
CV (%)	29.3	8.9	21.3	7.0	25.9	8.9	31.9	15
Soil Amendment								
PM	39.8	32.46	37.1	43.31	15.68	17.51	5.03	5.93
NPK	42	32.05	35	42.26	15.65	18.77	4.98	6.36
HR	42.2	32.62	36.4	44.3	14.84	16.53	4.43	5.66
NA	44.7	31.49	33.9	43.84	14.16	17.68	4.59	6.21
Lsd (0.05)	N/S	N/S	N/S	N/S	N/S	1.31	N/S	N/S
CV (%)	29.3	8.9	21.3	7	25.9	8.9	31.9	15

N/S = no significance, NT = no tillage, H = hoe tillage, PP = plough plant tillage, PH = Plough – harrow tillage, LM = large macro aggregates, SM = small macro aggregates, M = microaggregates, S+C = silt and clay fraction, PM= poultry manure, NPK = NPK 15:15:15 + Urea; HR = NPK + PM; NA = no amendment

Impacts of tillage on soil fractionation differed significantly (< 0.05) for all the soil aggregate fractions under the different tillage practices (Table 4.7). Hoe tillage plots had the highest LM fraction both at 0 – 15 cm and 15 – 30 cm depths of soil (47.70 and 35.78 %), whereas PP plots had the least LM fractions at both soil depths (37.60 and 32.84 %). More SM fraction were found on NT plots than on the other tillage plots at the 15 – 30 cm depth. Ploughed and harrowed plots had more SM fractions relative to the other tilled plots at 0 – 15 cm depth (Table 4.7).

The least SM fractions at 0-15 cm and 15-30 cm depth were recorded on the H plots and PP plots respectively. More microaggregates (M), and S+C fractions were recorded at both soil depths on the PP plots. The plots that were hoe tilled however, recorded the lowest micro aggregate fraction at both depths. For silt and clay fractions, H plots had comparatively lower fractions at the upper depth whereas plots that were not tilled had the lowest at the lower depth (15-30 cm).

Conventional tillage leads to less stable macroaggregate formation due to the continuous soil perturbation (Puget *et al.*, 1995) and soil aggregation, according to Bronick and Lal (2005), is higher in non-to-less disturbed soils than disturbed soils.

Plough plant and PH plots had comparatively the lowest LM fractions (Table 4.7) because of pedoturbation significantly influencing macro aggregates amounts. Effect of pedoturbation is reported to be more significant on macroaggregates than microaggregates (Six *et al.*, 2002). In effect, PP and PH practices selectively broke down macro aggregates but most of the micro aggregates were probably unaffected.

Selective breakdown of more macroaggregates than microaggregates by conventional tillage could be attributed to the binding agents within micro aggregates which may be resistant to the level of perturbation experienced. Similar observations were made by Six *et al*. (1999b); Denef *et al*. (2001); and Bossuyt *et al*. (2002).

More LM fractions in the top soil (0-15 cm) of the NT plot (Table 4.7) can be attributed to the decomposition of organic materials (maize stover) left NT plots surfaces resulting in the increased mineralization of carbon, encouraging more macro aggregation. (Fransluebbers and Arshad, 1997; Franzluebbers *et al*., 1999). According to Watts *et al*. (2001), plant residue breakdown forms organic mat for soil aggregation which is mostly concentrated at the soil surfaces.

The method used for soil separation (wet sieving) could also account for the amounts of soil separates measured. Sainju (2006), measured lower amounts of LM (>2 mm) and higher SM fraction (0.25 mm-2 mm) fractions. However, both fractions (SM and LM) were higher than the quantities of M and the S+C fractions when wet sieving was used. Lower proportions of LM fractions obtained through wet sieving resulted from rapture of weak aggregates in water because of ion hydration, sudden release of internal air pressure, osmotic swelling forces and solubility of binding agents in water and these processes are best activated by perturbation associated with plough plant, ploughing and harrowing are reason for low LM fractions under conventional tillage practices of the top soil (Table 4.7). (Perfect *et al*., 1990; Gale *et al*., 2000)

Effect of soil amendments on soil fractionation was statistically similar ($p > 0.05$) in the soil fractions except for M fractions of soil at the 15 – 30 cm (Table 4.8). Microaggregate fractions within the subsoil (15-30 cm depth) were significantly influenced by the application of chemical fertilizer (NPK) more than the other soil amendments applied. Chemical fertilizers (NPK) do not directly affect aggregation because it is not a binding agents of soil aggregates, however, it influences rate of organic matter decomposition hence could have stimulated organic matter breakdown leading to the formation of more microaggregates within the subsoil (15-30 cm depth).

This confirms reports by Bronick and Lal (2005), Yu *et al*. (2012) and Zhang *et al*. (2015) that, chemical fertilizer (NPK) cause less aggregation because of less diverse organic matter availability. In essence, the application chemical fertilizer (NPK) with organic manure increases aggregation by accelerated integration of the fine particles into coarse element

Interactive effects were established between the tillage practices and various soil amendments on the various soil fractions (Figures 4.5 and 4.6). Combining tillage practices and soil amendments significantly influenced ($p < 0.05$) soil aggregate fractionation for all the soil fractions in the 15-30 cm depth but not 0-15cm sampling depths.

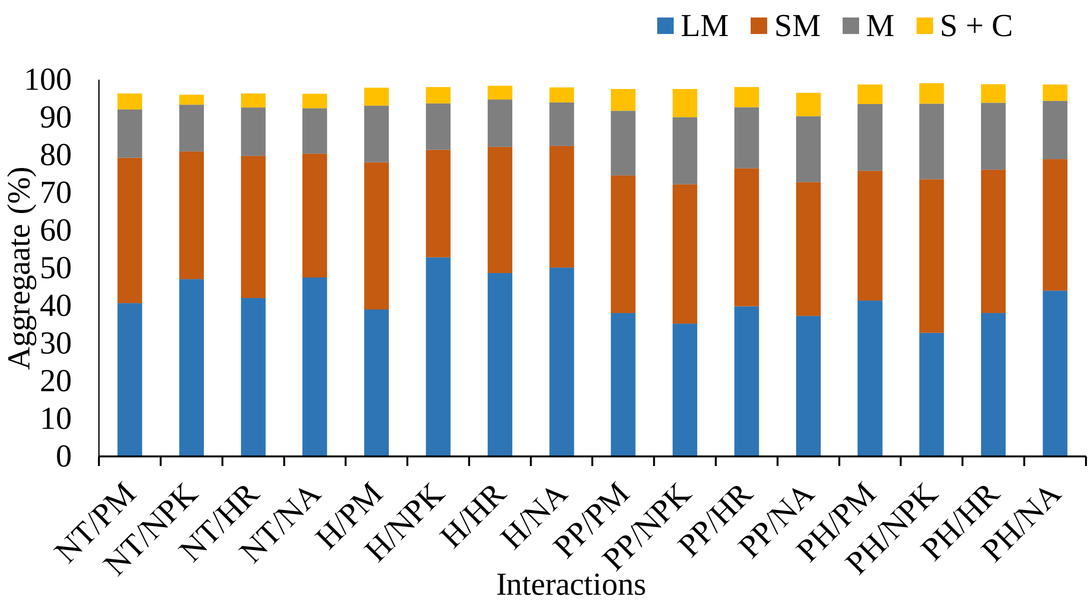


Figure 4.5. Interactive effects of tillage practices and fertilizer amendments on soil aggregate fractionation from soils sampled at 0-15 cm depth

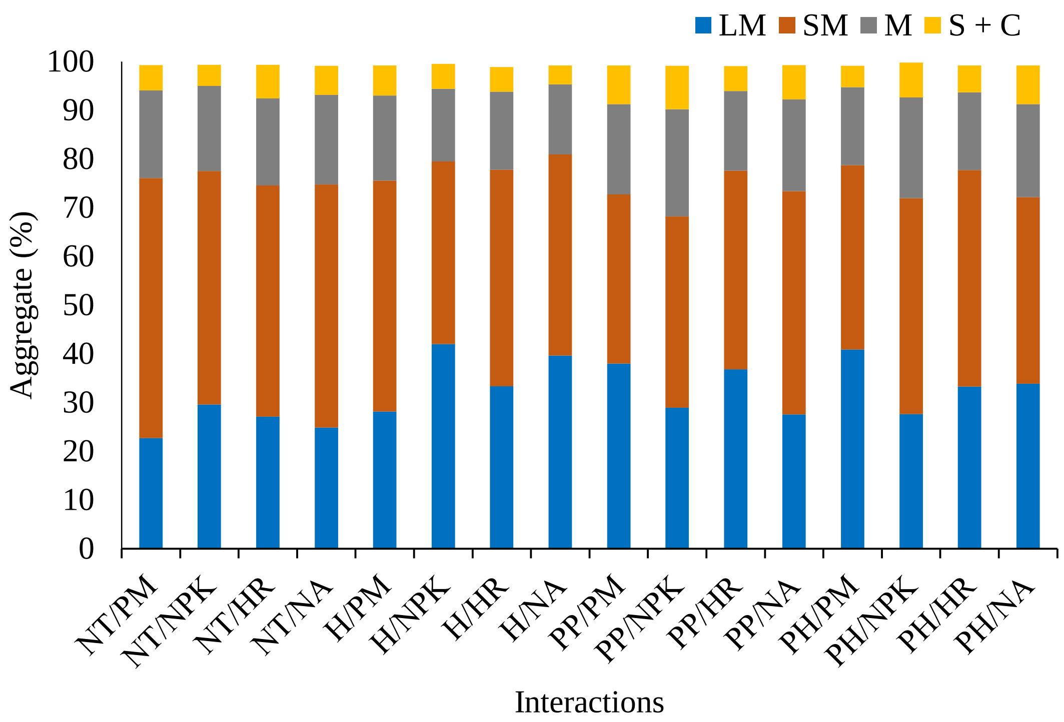


Figure 4.6. Interactive effect of tillage practices and fertilizer amendments on soil aggregate fractionation from soils sampled at 15-30 cm soil depth

Hoe tillage plus NPK amended plots recorded the highest interactive effect (52.9 % and 42 %) on LM fractions within the topsoil and subsoil (Figures 4.5 and 4.6). Plough harrow plus NPK amendment and NT/PM influenced the highest SM fractions (53.33% and 40.8 %), within 0-15 cm and 15-30 cm depths respectively. At both soil depths (0-15 and 15-30 cm), PP/NPK and PH/NPK recorded more M (22.03 % and 20.07 %) whereas the highest S+C fractions (7.54% and 7.98 %) influenced by PP/NPK and PH/NA respectively.

From Figures 4.5 and 4.6, proportions of LM fractions, influenced by the various interactions, were generally higher in the 0-15 cm depth than the other fractions whereas in the 15-30 cm depth, SM fractions were higher generally than the other aggregate fractions.

Lowest fractions were the S+C fractions under all the interactive effects. Paying attention to the 15-30 cm depth which recorded significant influence on the proportions of the various aggregate fractions, phosphorus component of the NPK fertilizer applied probably contributed to soil aggregation, explaining the higher LM fraction under H/NPK system (Figure. 4.6). Zhang *et al*. (2015) recorded increasing proportions of LM fractions with phosphorus amelioration. Bronick and Lal (2005) observed more aggregation with chemical fertilizer in less disturbed soils than in disturbed soils.

Under NT, there is increased biological activity which leads to the production of organic by- products that bind soil particles together during aggregation (Madejón *et al*., 2009; Plaza-Bonilla *et al*., 2013). These biological processes are enhanced by the application of poultry manure to the system. This could probably account for the higher small macro aggregates under the NT/PM system. Conventional tillage results in macro aggregates, held by weak bonds of fungal hypha and plant roots, to break down into the micro aggregates that resides in the macro aggregates (Six *et al*., 2000). Soil turn over results in microbial breakdown of organic matter into more humic forms which become the binding agent for micro aggregation (Zheng *et al*., 2008).

Ploughing and ploughing and harrowing breaks soil aggregates into small fractions which are the clay and silt fraction and the micro aggregates which are held by more recalcitrant organic binding agents. Mineral fertilizer (NPK) application could have possibly increased nitrogen content which accelerated soil organic matter decomposition because of a more favourable C:N ratio (Taylor *et al*., 2012). Hence, the combined effect on NPK application and PP and PH tillage resulted in the formation of more micro aggregates and silt at clay fractions at the 15 – 30 cm soil depths (Blanco-Canqui and Lal, 2004).

4.5 Carbon stocks within various soil aggregates

Soil carbon stocks in the aggregate fractions after three years are presented in Table 4.8a. Generally, redistribution of soil organic carbon of the bulk soil was observed in the soil aggregates.

The overall highest organic carbon stock (20.49 t C/ha), in soil fractions was recorded in the LM aggregate under the NT plots in the topsoil (0 – 15 cm) (Table 4.8a). This may be due to the higher amount of residue left on the soil surface of the NT plots and the less disturbance and soil turn over, which probably enhanced the macro aggregation. This affirms a report by Angers and Chenu (1998), Six *et al*. (1999a) and Yang *et al*. (2013), that soil organic carbon accumulation with the macroaggregates was a function of the soil structure stability hence soils with less disturbance tends to enhance soil organic carbon storage at the topsoil.

The least carbon stocks from the LM fractions in the 0-15 cm depth (3.85 t C/ha) was recorded on PH plots (Table 4.8a). Similar trends were observed for the carbon stocks in SM fractions. Highest carbon stocks of the microaggregate fraction (8.19 t C/ha) and silt and clay fraction (4.04 t C/ha) in the 0-15 cm soil depth were recorded under the PP plots (Table 4.8a). The lowest carbon stocks in the M fraction (5.12 t C/ha) and the silt and clay fractions (1.91 t C/ha) were recorded under the PH plots.

Table: 4.8a. Carbon stocks within the various soil fractions as affected by tillage practices

Tillage	LM (> 2000 µm)		SM (250-2000 µm)		M (53-250 µm)		S+C (< 53 µm)		Total	
	0-15	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
NT	20.49	5.25	13.61	14.68	7.71	7.98	3.50	3.24	45.31	31.15
H	15.41	7.62	9.95	11.60	8.07	7.44	3.70	3.30	37.13	29.96
PP	9.95	6.36	8.92	10.22	8.19	9.93	4.04	4.87	31.1	31.38
PH	3.85	5.77	3.85	9.65	5.12	7.00	1.91	3.96	14.73	26.38
Lsd (0.05)	5.083	1.031	2.66	1.005	1.69	0.76	0.91	0.64	9.82	3.436
CV (%)	49.1	19.8	35.1	10.5	27.9	11.3	33.0	20.0	15.3	5.8
Soil Amendment										
Pm	10.85	5.73	9.22	12.03	7.63	8.03	3.63	4.17	31.33	29.96
NPK	12.49	6.24	9.68	10.59	7.64	8.76	3.44	4.01	32.43	29.6
HR	12.70	5.43	8.87	12.33	7.41	7.60	3.08	3.41	32.87	28.77
NA	13.66	7.60	8.55	11.19	6.41	7.96	3.00	3.78	31.62	30.53
Lsd (0.05)	N/S	1.031	N/S	1.005	N/S	0.761	N/S	N/S	N/S	N/S
CV (%)	49.1	19.8	35.1	10.5	27.9	11.3	33.0	20.0	15.3	5.8

Soil organic carbon stocks (t/ha); Soil Aggregate Fractions; Depth class (cm)

N/S = no significant difference, NT = no tillage, H = hoe tillage, PP = plough plant tillage, PH = Plough – harrow tillage, PM = 3 t/ha poultry manure, NPK = 60-40-40 NPK + urea, HR = 30-20-20 NPK + 1.5 t/ha poultry manure, NA= no amendment, LM = large macro aggregates, SM = small macro aggregates, M = micro aggregates, s+c = silt and clay fraction, Lsd = least significant difference, CV = coefficient of variation.

Within the subsoil (15 – 30 cm depth), the highest carbon stocks for the LM fraction (7.62 t C/ha) was influenced by H tillage whereas NT contributed to higher carbon stocks (14.68 t C/ha) within the SM fractions. Plough plant significantly influenced higher carbon stocks, 9.93 t C/ha and 4.87 t C/ha, within the microaggregates and the silt and clay fractions respectively (Table 4.8a). The least carbon stocks for LM (5.25 t C/ha) and silt and clay fractions (3.24 t C/ha) in the subsoil were recorded in the NT plots (Table 4.8a). This could be due to less soil turnover and carbon redistribution as well as organic material incorporation into the soil.

Plough harrow on the other hand has the least carbon stocks in the SM (9.65 t C/ha) and M fractions (7.00 t C/ha). Hoe tillage do not completely break and turn the soil and so may explain the reason why the carbon stocks within the SM fractions were more under the H plots.

The physical protection of carbon in the macroaggregates were probably destroyed during the plough plant and the ploughing and harrowing and so resulting in their comparatively low carbon stocks within the macro aggregates (Six *et al*., 1998; Blanco – Canqui and Lal, 2004). Also, the very low carbon stocks of the various soil fractions under PH plots was due to the continuous disturbance of the soil exposes the otherwise protected carbon to microbial activity which might have led to a drastic fall in SOC and soil structure interaction resulting in micro aggregates with depleted C being formed (Blanco – Canqui and Lal, 2004).

Resck *et al*. (1999) suggested that, the use of disk plough and heavy disk plough cause a great loss of organic carbon from the soil because of the destruction of the physical protection of the organic carbon. Santos *et al*. (1997) observed little difference between carbon stocks of an area that was disk ploughed and an area that was harrowed with a heavy disk harrow even though both had appreciably less carbon stocks. Plough harrow plots influenced lower carbon stocks within some of the soil fractions because ploughing and harrowing broke the soil aggregates into smaller particles making the soil highly susceptible to wind and water erosion and so most of carbon might have been washed or carried away through selective erosion (Lal, 1997).

The effect of soil amendment on carbon stocks within the soil fractions was not significantly different ($p > 0.05$) in the topsoil but was significantly different at the subsoil except the silt and clay fraction. The effect of soil amendment on carbon stocks of the LM, SM and M fractions at the subsoil decreased in the order of NA> NPK >PM> HR; HR > PM > NA > NPK; and NPK > PM>NA> HR respectively.

Notwithstanding statistical similarities of the effect of some soil amendments, NA plots had highest carbon stocks (Table 4.8a) within the LM fractions at the 0-15 cm and 15-30 cm affirming that, the effect of soil amendment on carbon storage within soil aggregates rest on other factors such as climatic variables (Baldock, 2008) hence, the soil amendments applied could not influence higher carbon stocks within the LM fraction.

Carbon stocks within silt and clay fractions and M fractions at both depth and was increased by PM and NPK respectively. Highest carbon stocks in the SM in topsoil and subsoil were recorded for NPK and HR respectively. Poultry manure contains appreciable amount of carbon that might have increased rate of mineralization of carbon by increasing microbial build up, hence influenced carbon stocks in the silt and clay fractions (Zhang *et al.*, 2015). Also, chemical fertilizer probably encouraged preferential carbon storage within the microaggregates fraction (Sainju, 2006).

Interactive effect of tillage with soil amendment on carbon stocks within the soil aggregates were significant ($p < 0.05$) only at 15 – 30 cm depth (Figure 4.7). In the 15-30 cm depth, PP/PM plots influenced higher carbon stocks in the LM, microaggregate and silt and clay fractions. NT/PM influenced higher carbon stored in the SM fractions (Figure 4.7).

Comparatively, the NT/PM stored more carbon in the SM fraction (19.43 t C/ha) than was stored by PP/PM in the other aggregate fractions (10.47 t C/ha, 11.53 t C/ha and 5.96 t C/ha for LM, M and silt and clay fractions respectively). From Figure 4.7, even though NT/PM gave the highest carbon stocks within the small macro aggregates, PP/PM, stored cumulatively 2.98 t C/ha more than NT + PM (Figure. 4.8). The least total carbon storage in all the soil fraction was recorded under PH + PM which was 15.97 t C/ha less than carbon stored by the PP/PM system.

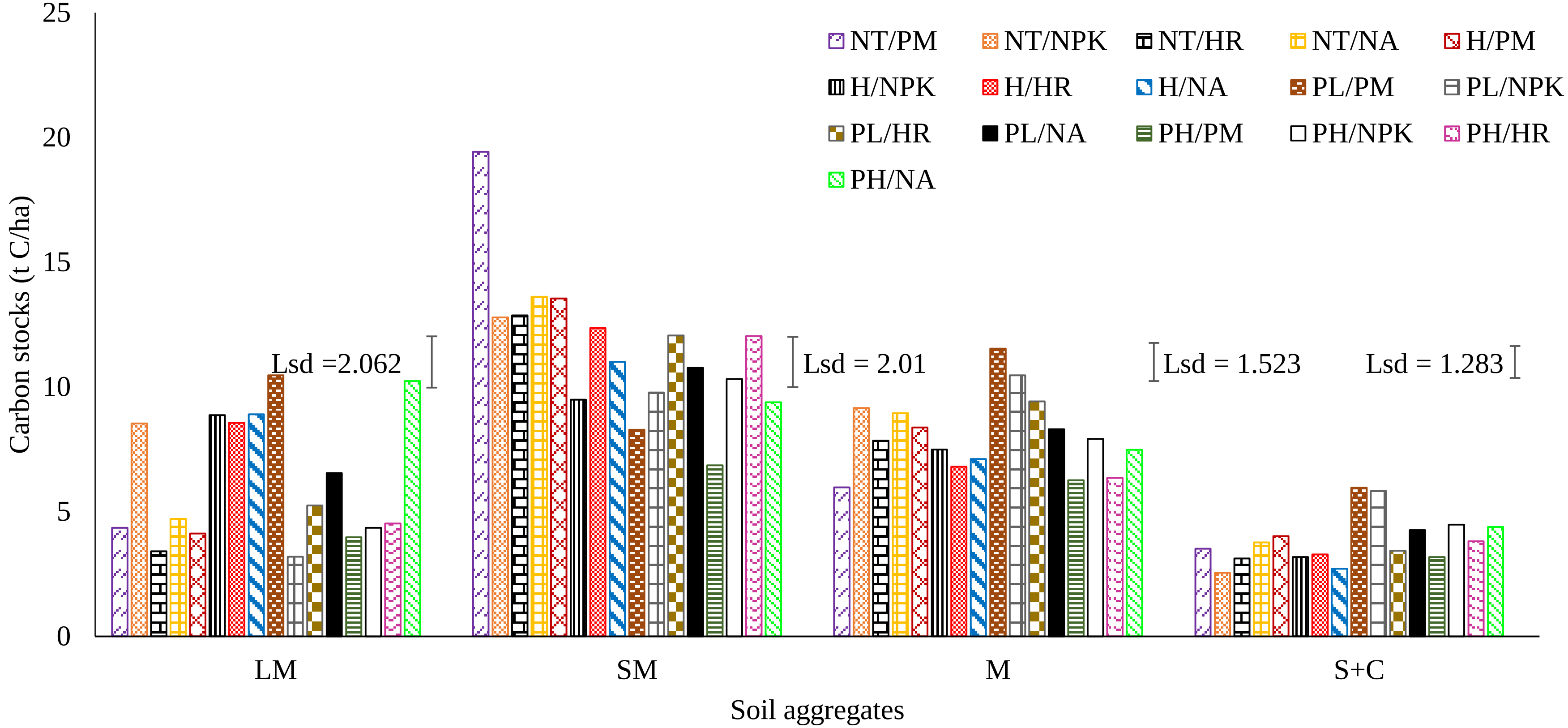


Figure. 4.7. Interactive effect of tillage and soil amendment on carbon stocks within soil aggregates at 15 – 30 cm depth.

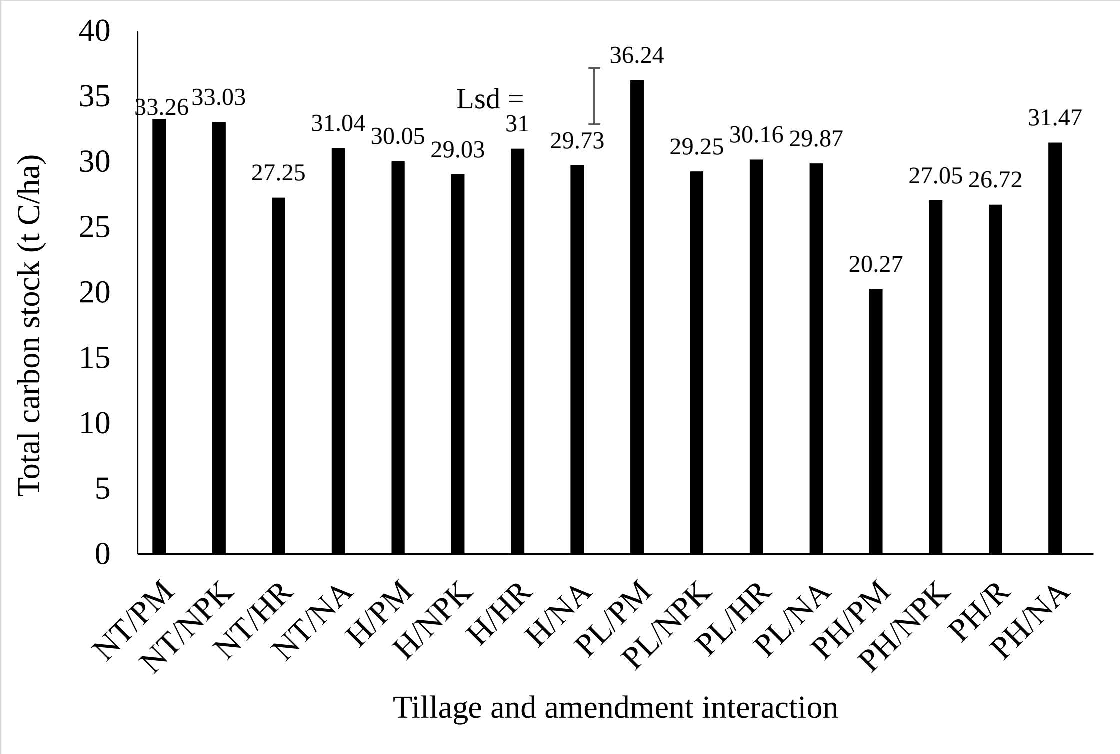


Figure 4.8. Cumulative carbon stored by the interactive systems employed

Tillage mostly influence depth distribution of soil organic carbon more than soil organic carbon accumulation (Yang and Wander, 1999; Gál *et al*., 2007; Hermle *et al.*, 2008; Angers and Eriksen – Hemel, 2008). Despite the results in Figures 4.5 and 4.6, PP/PM incorporated more carbon in three out of the four soil fractions whereas NT/PM stored the most carbon in the SM fractions (0.25 mm-2 mm). It can also be inferred from Table 4.8 and Figures 4.7 and 4.8 that PP and PP/Pm showed potential of soil organic carbon sequestration than other tillage practices and interactions because they influenced higher carbon stocks in the microaggregates and silt and clay fractions. Six and Paustian (2014) and Sheehy *et al*., (2015) suggested that, the carbon stocks in the microaggregate fraction could serve as a robust indicator for how quickly or otherwise soil organic carbon could be lost signifying carbon loss or carbon sequestration.

Conventional tillage practices (ploughing) incorporates organic materials into the soil rather than leave them on the soil surface. This leads to increased carbon stocks at lower levels of the soil. A study by Poirier *et al*. (2009) showed increasing soil organic carbon under plough plant plots at lower depths of the soil (20 – 30 cm) and observed higher soil organic carbon under PP plots than no till plots. Subsoil conservation of carbon by ploughing increases the soil organic carbon protection and increases sequestration (Lorenz and Lal. 2005; Sheehy *et al*., 2015). According to Figure 4.7, even though NT/PM effect influenced the highest soil organic carbon, PP/PM stored most of the soil organic carbon within the microaggregates which is known to protect organic carbon better. This will hold the soil organic carbon for longer periods as soil organic carbon types held within micro aggregates are less vulnerable to microbial breakdown (Blanco-Canqui and Lal, 2004). Also, plough plant probably increased the surface area of the poultry manure incorporated eventuating in heightened mineralization of soil organic carbon and subsequently being shielded in aggregates formed at the subsoil depth (Taylor *et al*., 2012).

PP/PM stored more soil organic carbon in the clay and silt fraction which is suggested to protect and stabilize soil organic carbon better especially at deeper soil depths (Poirier *et al*., 2009). Stemmer *et al*. (1999) adds that, organic matter is more decomposed when mixed with the soil, resulting in SOC incorporated within silt and clay fractions. Plough plant plus PM might have encouraged more adsorption of the humified PM to the mineral surfaces which are mostly effective in adsorption within the subsoil. (Kaiser and Guggenberger, 2003). Stemmer *et al*. (1999) concluded that, more soil organic carbon may be stored in tilled than no till plots. PP/PM stored more soil organic carbon within the LM fraction at the 15 – 30 cm depth.

Rasse *et al*. (2006), suggest that, fine root activity, microbial activity and movement of dissolved soil organic carbon may have resulted in soil organic carbon accumulation within large macro aggregates within ploughed soils. Particulate organic carbon can be leached downwards and this could account for the higher soil organic carbon stocks within the small macro aggregates under the no till at 15 – 30 cm soil depth.

4.5.1 Soil organic carbon sequestration potential

Soil organic carbon stocks within the microaggregate fraction which is reported as the most stable state and indicator of soil carbon sequestration (Six *et al.*, 1998; Whalen and Chang, 2002; Kong *et al*., 2005) are presented in Table 4.8b below. Tillage practices significantly ($p < 0.05$) influenced carbon stocks in the microaggregates in the 0-30 cm depth. Plough plant plots recorded the highest carbon stocks within the microaggregates (18.12 t C/ha) and was significantly different from the other tillage effects. Plough harrow (12.12 t C/ha) recorded the least carbon stocks in the micro aggregates over 30 cm depth from the soil surface.

Plough plant tillage probably did not pulverise microaggregates occluded in macroaggregate as in the PH tillage. The microaggregates are strongly bound by humic forms of organic carbon (Six *et al*., 2000; Zheng *et al*., 2008) which are able to resist soil disturbance.

Table 4.8b. Total microaggregate (over 30 cm) from the soil surface

Tillage	Carbon stocks (t C/ha) M (53-250 µm) 0-30 cm
NT	15.69
H	15.52
PP	18.12
PH	12.11
Lsd (0.05)	1.77
CV (%)	5.8
Soil Amendment	
Pm	15.66
NPK	16.4
HR	15.01
NA	14.37
Lsd (0.05)	N/S
CV (%)	5.8

N/S = no significant difference, NT = no tillage, H = hoe tillage, PP = plough plant tillage, PH = Plough – harrow tillage, PM = 3 t/ha poultry manure, NPK = 60-40-40 NPK + urea, HR = 30-20-20 NPK + 1.5 t/ha poultry manure, NA= no amendment, Lsd = least significant difference, CV = coefficient of variation.

This suggests that PP tillage has the potential of sequestering more stable soil organic carbon than other tillage practices over the 30 cm soil depth. Plough harrow, however, recorded the least soil carbon stocks in the microaggregates due to increased pulverization and heightened microbial activity which resulted in C-depleted microaggregates (Blanco-Canqui and Lal, 2004). Soil amendment had no significant influence on carbon stocks in microaggregates over the 30 cm soil depth. This was observed because soil amendment effect on carbon stock distribution in soil aggregates rest on other factors such as climatic conditions (Baldock, 2008)

4.6 Microbial biomass carbon

Soil microbial biomass carbon assessed is presented in Table 4.9 and Figure 4.9 below. There was interactive effect of tillage practices and soil amendments applied. Microbial biomass carbon forms part of the soil organic matter. It showed very high variability (Table 4.10) affirming a statement by Lupwayi *et al*. (1998) that soil microbial biomass carbon comprises little percentage of soil organic matter but is the most dynamic form of soil organic matter. Effect of tillage on microbial biomass carbon was not significantly different (p >0.05). However, PP plots recorded the highest MBC whereas NT plots had the lowest MBC. It was also noticeable that conventionally tilled (PP and PH) plots had more MBC compared to H and NT plots.

Table 4.9. Main effects of tillage and soil amendment effect on soil microbial biomass carbon

Tillage	**MBC (mg/kg)**
NT	667
H	735
PP	1002
PH	903
Lsd (0.05)	N/S
CV (%)	60.9
Soil amendment	
PM	748
NPK	1148
HR	721
NA	689
Lsd (0.05)	369.9
CV (%)	60.9

N/S = no significance, NT = no tillage, H = hoe tillage, PP = plough plant tillage, PH = Plough – harrow tillage, PM = poultry manure, NPK = NPK 15:15:15 + urea, HR = Half NPK + Half PM, NA= no amendment, Lsd = least significant difference, CV = coefficient of variation.

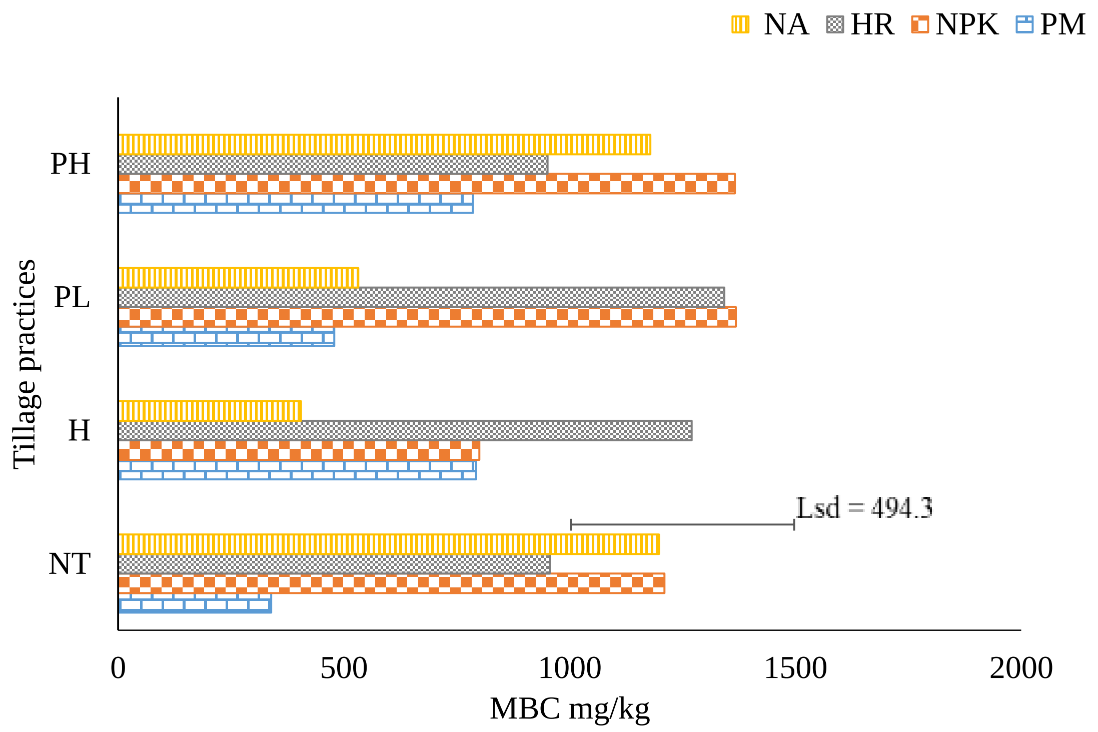


Figure 4.9. Interactive effect of tillage and soil amendments on microbial biomass carbon (mg/kg)

Ploughing increases the surface area of organic matter in the soil and pulverize the soil, improves soil porosity (Table 4.3) and increase entry of oxygen supply to the microbes enabling organic matter break down. These could have activated the increase of microbial population in the soil hence increase microbial biomass carbon. Low MBC under no tillage practices was, however, an unexpected outcome from the study even though there was no significant difference among the treatments because it recorded higher porosity (Table 4.3) and hence was to essentially increase microbial biomass. Guo (2014) observed that NT did not increased MBC more than conventional tillage (PP).

Soil amendments applied influenced ($p < 0.05$) the MBC significantly. In ascending order, soil amendment effect on MBC were NA > HR > PM > NPK. NPK significantly increased microbial biomass carbon. Soil microbial biomass carbon are the very labile forms of carbon with lower C:N ratio.

The NPK influencing more microbial biomass carbon could be related to increasing in the build-up of microbial population and hence increased rate of decomposition of carbon content of the various amended plots. Mohammadi *et al*. (2012) on the contrary observed, however, that integrated chemical fertilizer and organic manure increases MBC than their individual effects as both increase nitrogen and carbon content of the soil there which are the raw materials to microbial activities.

The highest and lowest interactive effects of tillage and soil amendment on MBC were recorded on PP/NPK and PH/PM respectively. This suggests that, the NPK application on the PP plots increased labile C content of the soil with the high supply of nitrogen which enhances increasing microbial population hence increased MBC content than other systems used (Lupwayi *et al*., 1998).

4.7 Carbon dioxide emissions under tillage and soil amendments.

Carbon dioxide emission measured on the field is presented in Figures 4.10 to 4.15.

Tillage operations generally influenced a rise in carbon dioxide emissions from 6 to 9 WAP except for emissions under the PH plot which experienced a slight decline from 6 to 7 WAP and 8 to 9 WAP as well as emission under PP from 8 to 9 WAP (Figure 4.10).

There was also a sharp fall of soil carbon dioxide emission from week four to week six. These rise and decline in carbon dioxide emissions over time indicates that the process depends on several factors, such as organic carbon content of the soil, quality of organic material supplied, soil temperature and soil moisture content.

The effect of tillage operations on carbon dioxide emissions was significantly different ($p < 0.05$) throughout the period of measurements. The highest carbon dioxide emission (11.72 g C/m^2/day) was recorded on the 4th week (9 WAP) of the emission study under NT plots.

On the average carbon dioxide emissions were significantly higher on NT plots than the tilled plots. Plough harrow, PP and H operations followed respectively in a descending order of amount of carbon emission. However, carbon dioxide emissions under PP and PH plots were significantly similar.

Higher carbon dioxide emissions in week one and two (6 and 7 WAP) were recorded on PH plots. No tillage plots had plant residue at their surfaces and the decomposition of these organic materials coupled with carbon mineralization led to increased carbon dioxide evolution from the NT plots than the other plots. According to Yang *et al.* (2013), carbon dioxide evolution under no till varies greatly with climatic conditions and quantity and placement of crop residue on the no till plots (Yang *et al.*, 2013). Nyakatawa *et al*. (2012) measured significant levels of carbon dioxide emissions only in summer and Prior *et al*. (2000) recorded higher carbon emissions under NT plots after rainy periods. This confirms that carbon dioxide emission depends on moisture and temperature among other factors.

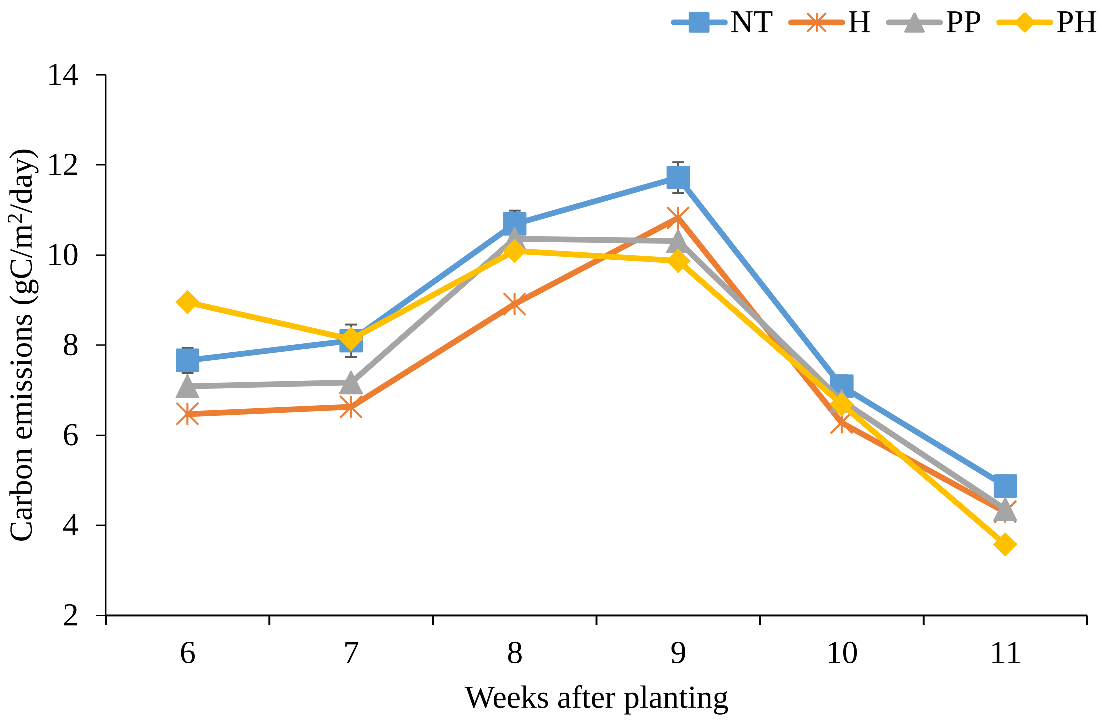


Figure 4.10. Tillage effect on carbon dioxide emission (gC/m2/day)

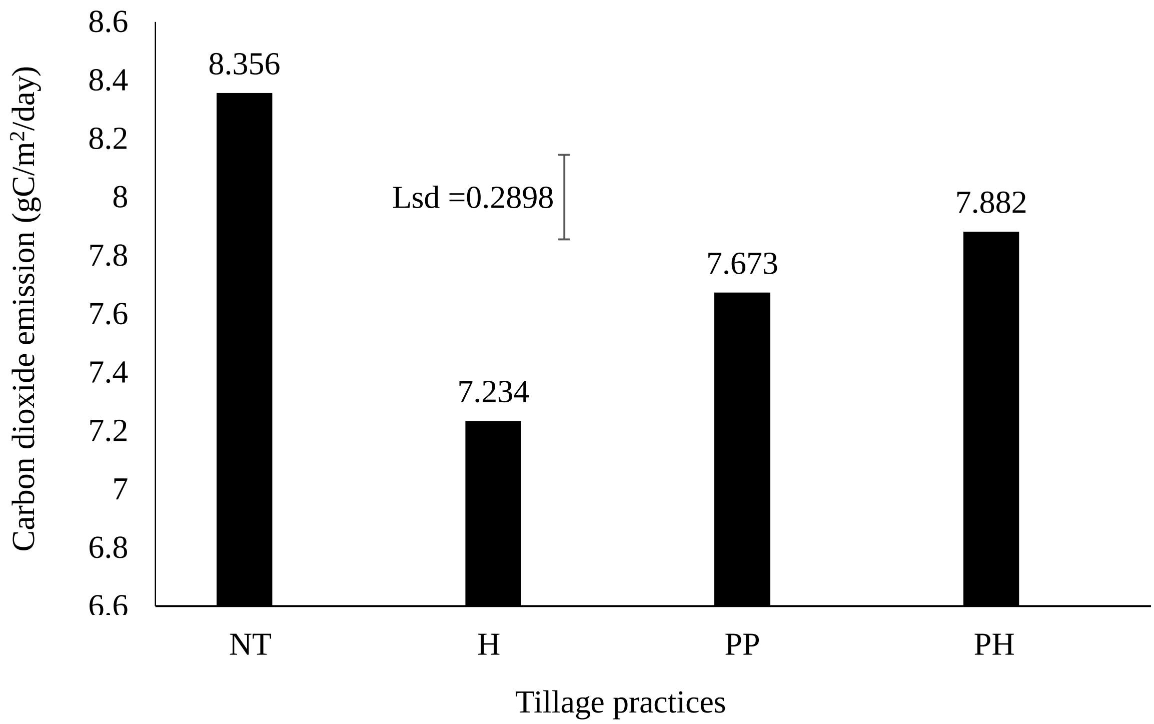


Figure 4.11. Average carbon dioxide emissions under different tillage practices

Even though NT plots recorded the lowest (30.03) average soil temperature (Table 4.7), it was appreciable enough to accelerate the rate of carbon mineralization especially at the surfaces of the NT plots. Silva-Olaya *et al*. (2013) measured 0.82 $gC/m^2/h$ from a site with average soil temperature of 23.6^oC indicating that the 30.03^oC temperature recorded NT plots was enough to influence carbon dioxide emissions. Conventional tillage temporarily increases carbon dioxide emissions at the initial stages but subsequently, its impact on emissions become negligible (Johnson *et al*., 2010). Ellert and Janzen, (1999) and Rastogi *et al*., (2002) observed that after 24 hours of tillage, there was similarity of carbon dioxide emission under no tillage and conventional tillage.

Ball *et al*. (1999) suggest that low emission is associated to low gas diffusivity due to low air-filled porosity. No till plots recorded the highest air-filled porosity (43.76%) relative to the other tillage operations (Table 4.3). Also, from Table 4.2, NT plots recorded the highest carbon stock (48.9 tC/ha) at topsoil (0 – 15 cm) depth. These factors may be responsible for to the higher carbon dioxide measurements recorded under the NT plots. Hendrix *et al*. (1988) and Fortin *et al*. (1996) and Aslam *et al*. (2000) observed similarities between NT and conventional tillage about their influence on carbon dioxide emissions.

Conversely, Ussiri and Lal. (2009), Al – Kaisi and Yin (2005) and Nyakaktawa *et al*. (2012) observed a higher carbon with conventional than no till plots which they reported to be as a result of carbon turnover and soil disturbance which accelerated carbon mineralization.

Tilling the soil opens the soil up exposing the capillary stream of the soil to the atmosphere, promoting mass air movement from the soil to the atmosphere (Bauer *et al*., 2006; Omonode *et al*., 2007; Robertson, 2008; Nyakatawa *et al*., 2012). However, opened streams in the absence of less carbon content within the topsoil depth would result in less quantities of carbon dioxide supply. In general, the effect of tillage on carbon dioxide emissions is variable since it is difficult simultaneously establish controlled conditions. (Kessavalou *et al*., 1998b).

Effect of soil amendments on carbon dioxide emissions was significantly different at all sampling dates (Figure 4.12). Consistently, higher carbon dioxide measurement per week was influenced by a different soil amendments.

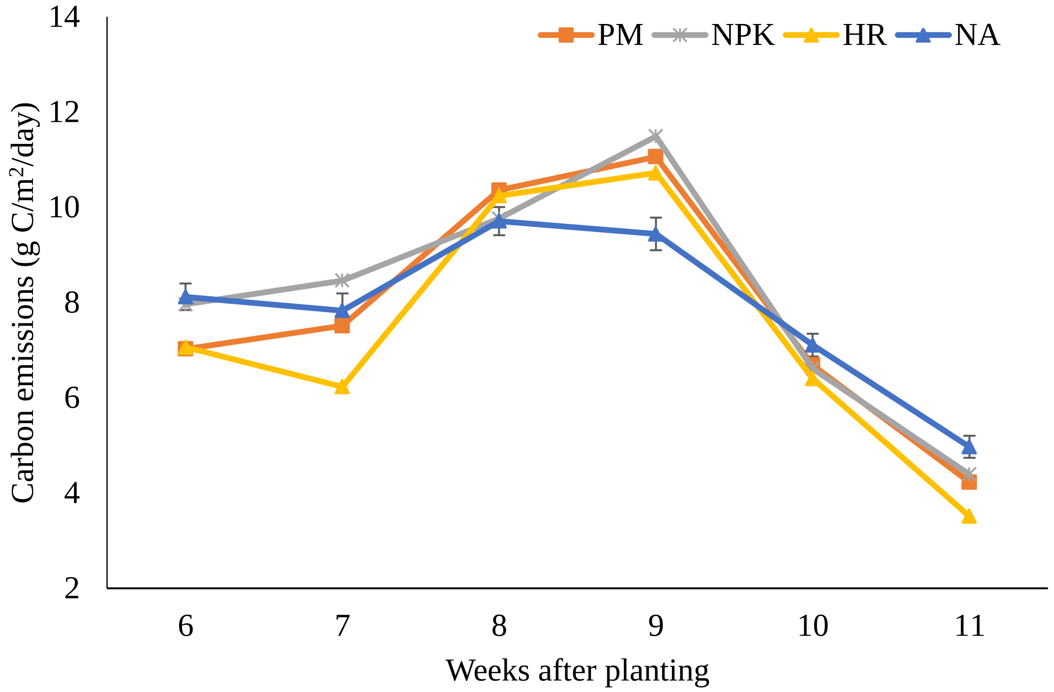


Figure 4.12. Influence of soil amendment on carbon dioxide emissions

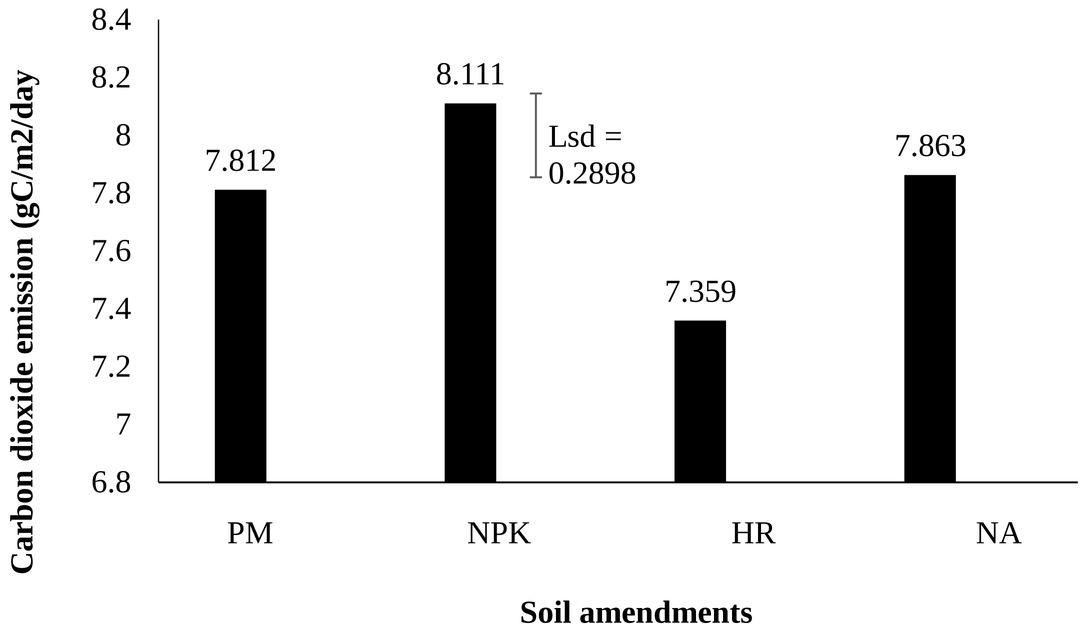


Figure 4.13. Average carbon dioxide emissions under different soil amendments.

The soil amendment which gave the highest carbon evolution differed from week to week. Soil amendments significantly caused a rise in carbon dioxide emission from week one to week 4 and a sharp fall from week 4 to week 6 except for HR (Half PM + Half NPK and Urea) which dropped at week two and NA amended plots which dropped slightly at week 2 and week 4.

No soil amendment plots recorded the highest carbon dioxide emission for week one, five and six whereas NPK influenced the highest emission from week 2 to 4.

Average carbon dioxide emissions recorded under NPK amended plots were significantly different ($p < 0.05$) from the other soil amendments applied and recorded the highest promoter to carbon dioxide emissions above PM, HR and NA.

Averagely, NPK increased carbon emissions than PM and other soil amendments applied (Figure. 4.13). Carbon dioxide emission occurs through microbial respiration (Johnson *et al.*, 2007). Applying nitrogenous fertilizers affects carbon dioxide emission because it directly increases microbial build up through nitrogen provision and also slightly affect soil pH which affect microbial activity (Rastogi *et al*., 2002).

Nitrogen application to the soil forms strong relationship with labile carbon leading to increased carbon dioxide emissions. Heller *et al*. (2010) found that, high percentage of carbon dioxide emission variability is linked to the N content of the soil solution.

Organic waste decomposition results in higher volumes of carbon dioxide emission and this is highly influenced by nitrogen availability (Heller *et al*., 2010). Earlier, Hadas *et al*. (1998) reported that availability of inorganic N may influence organic matter decomposition and subsequent carbon dioxide emission into the atmosphere. Also, Jacinthe and Lal (2005) showed that N application increases humification which eventuate in heightened carbon dioxide emissions. Feiziene *et al*. (2012) observed that mineral NPK fertilizer promoted higher carbon dioxide exchange.

This affirmed in this study as NPK resulted in higher carbon emissions which could be attributed to heightened microbial activity resulting in increased humification and resultant higher carbon dioxide emission (Sommer and Hutchings, 2001; Rochette *et al*., 2004; Sharpe *et al*., 2004).

On the contrary to the findings of this study, Hadas *et al*. (2004), Jones *et al*. (2005) and Ding *et al*. (2007) found that poultry manure contributes to high carbon emissions. Heller *et al*. (2010) measured higher carbon dioxide emissions on plots amended with poultry manure and emission peaked after the application of poultry manure.

Figures 4.14 and Table 4.10 show the weekly interactive effects on carbon emission. From Table 4.10, carbon dioxide peaked at week four and was lowest at week six.

Least emissions per week were recorded under H/ HR system and highest under NT/NPK (Table 4.10). Average interactive effects on carbon dioxide emissions (Figure 4.14) were highest under NT/NPK followed closely by NT/PM as both systems had significantly similar effects on carbon dioxide emissions.

Least average carbon dioxide emissions were recorded under the H/ HR which was also not different ($p > 0.05$) from emission by PP/PM system (Figure 4.14). NPK on no till plots gave out the highest carbon dioxide because of the residue on the surface of the NT plots and the accelerated decomposition of the residue due to application of NPK and subsequent build-up of microbial activity eventuating higher carbon dioxide emissions. Application of mineral N reduced the C:N ratio of the residue and hence improved easier crop residue break down. No till plots as mentioned earlier were porous enough (Table 4.3) to improve gas diffusivity which is important for carbon dioxide loss from the soil (Figure 4.14). The lowest carbon emissions recorded for H/ HR and PP/PM were probably because the poultry manure was incorporated into the soil rather than left on the soil surface, hence its breakdown did not increase the carbon dioxide concentration in the immediate atmosphere (Figure 4.14).

Heller *et al*. (2010) observed that tilled plots which were poultry manure amended emitted appreciably less carbon dioxide than NT/PM plots. This is because of the placement of manure by the various tillage practices, PP incorporates while NT leaves on the soil surface.

Table 4.10. The combined effect of tillage and soil amendment on carbon dioxide emissions

Tillage/ amendment interactions	Carbon Dioxide Emissions (g C/m^2/day) Weeks After Planting (WAP)					
	6	7	8	9	10	11
NT/PM	8.88	8.55	11.04	12.34	6.81	4.34
NT/NPK	8.42	9.01	10.37	12.65	8.25	4.59
NT/ HR	5.56	5.78	10.98	11.64	6.37	4.54
NT/NA	7.79	9.06	10.39	10.24	6.92	6.02
H/PM	5.48	7.43	9.43	11.61	8.057	4.78
H/NPK	8.13	8.72	8.32	10.82	4.61	4.77
H/ HR	5.00	4.74	8.73	10.47	5.96	2.78
H/NA	7.28	5.64	9.16	10.37	6.48	4.84
PP/PM	3.96	5.68	9.62	9.29	5.94	4.01
PP/NPK	6.63	8.46	11.40	12.21	6.71	4.71
PP/ HR	8.94	6.20	10.82	10.54	6.97	3.85
PP/NA	8.80	8.32	9.62	9.19	7.43	4.86
PH/PM	9.78	8.38	11.34	11.00	5.94	3.76
PH/NPK	8.67	7.64	8.93	10.26	6.88	3.49
PH/ HR	8.74	8.19	10.43	10.23	6.32	2.88
PH/NA	8.61	8.30	9.65	7.97	7.60	4.16
Lsd (0.05)	1.12	1.43	1.19	1.37	0.95	0.93
CV (%)	26.5	30	16.1	18.5	23	27.2

NT/PM = no till/poultry manure, NT/NPK= no till/60-40-40 NPK 15-15-15 + urea, NT/ HR = no till/ 30-20-20 NPK 15-15-15 + Half Urea + 1.5 t/ha poultry manure, NT/NA = no till/no amendment, H/PM = hoeing/poultry manure, H/NPK= hoeing/60-40-40 NPK 15-15-15 + urea, H/ HR = hoeing/ 30-20-20 NPK 15-15-15 + Half Urea + 1.5 t/ha poultry manure, H/NA = hoeing/no amendment, PP/PM = plough plant/poultry manure, PP/NPK= plough plant/60-40-40 NPK 15-15-15 + urea, PP/ HR = plough plant/ 30-20-20 NPK 15-15-15 + Half Urea + 1.5 t/ha poultry manure, PP/NA = plough plant/no amendment, PH/PM = plough harrow/poultry manure, PH/NPK= plough harrow/60-40-40 NPK 15-15-15 + urea, PH/ HR = plough harrow/ 30-20-20 NPK 15-15-15 + Half Urea + 1.5 t/ha poultry manure, PH/NA = plough harrow/no amendment, Lsd = least significant difference, CV = coefficient of variation.

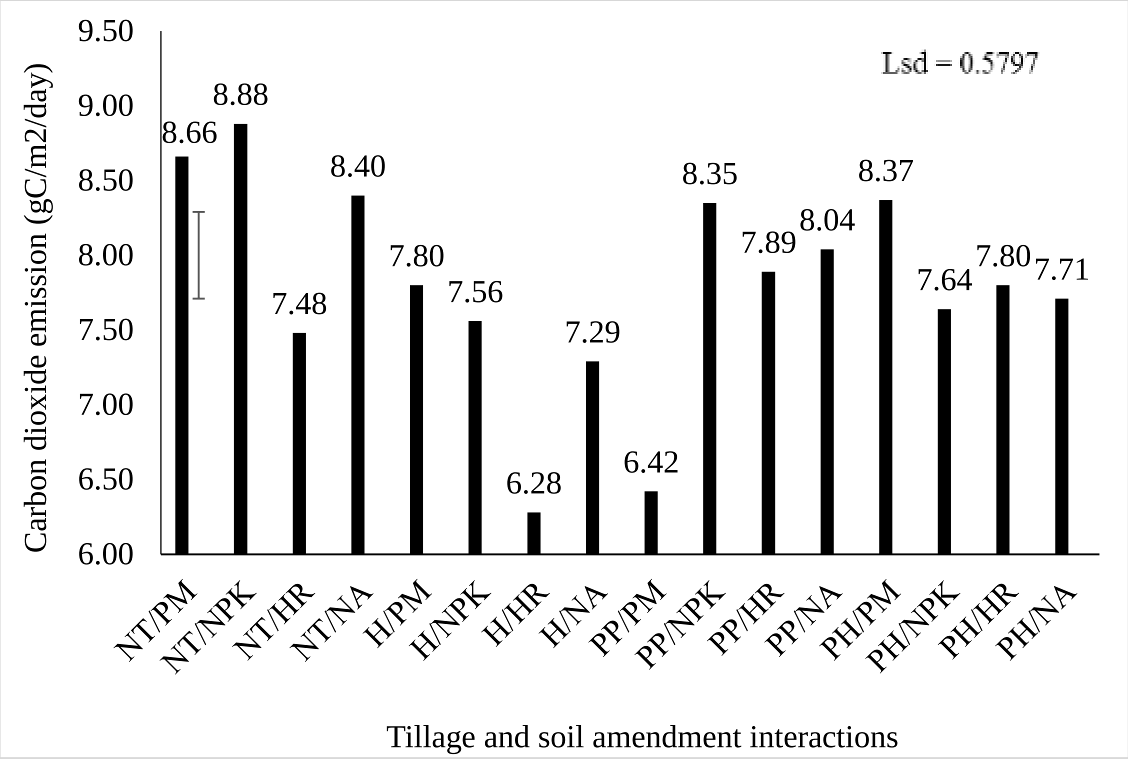


Figure 4.14. Interactive effects of soil amendments and tillage practices on average carbon emissions.

Comparing interactive effect of tillage and soil amendments on carbon storage within the aggregates and carbon dioxide emission (Figure 4.9), it could be inferred that, NT lost most of its organic carbon through carbon dioxide emission hence recording more carbon dioxide emission than PP system.

4.8 Correlation analysis between emission, soil moisture and temperature

Table 4.11. Coefficient of correlation between soil organic carbon stocks, soil moisture, soil temperature, microbial biomass carbon and soil carbon dioxide emissions

	Soil CO_2 emission	**Soil moisture**	**Soil temperature**	**SOC stocks (0-15cm)**	**SOC stocks (0-15cm)**	**MBC**
Soil CO_2 emission	-					
Soil moisture	0.2866 *	-				
Soil temperature	-0.3817**		-			
SOC stocks (0-15 cm)	NS	NS	NS	-		
SOC stocks (15-30 cm)	NS	NS	NS	0.2581**	-	
MBC	NS	NS	NS	NS	NS	-

MBC = Microbial biomass carbon, ** = $p < 0.01$, * = $p < 0.05$, NS = not significant.

There was significant positive relationship established between soil moisture content and carbon dioxide emission. No till plots from Table 4.8 recorded the lowest soil temperature but increased carbon dioxide emission. Nyakatawa *et al*. (2012) observed positive correlation between soil temperature and carbon dioxide emissions. From Figure 4.3, peak soil moisture measured at week four significantly increased soil emissions at 9 WAP especially in the NT plots. Silva – Olaya *et al*. (2013), observed similar trends of positive corelation between soil moisture and soil carbon dioxide emissions. Correlation between soil carbon emissions and MBC and soil organic carbon stocks at both soil depths measured was not significant.

Also, no good fits of correlation was observed between microbial biomass C and organic carbon measured at both soil depths. This conforms the findings of Insam and Domsch (1989) and Zak *et al*. (1994) who reported no significance between soil organic carbon and microbial biomass carbon. Leirós *et al.* (2000), observed positive correlation between soil organic carbon and soil microbial biomass carbon. These inconsistencies could be explained by the fact that soil microbial communities are affected by organic carbon quality and microbial community structure and the soil type (Leirós *et al.*, 2000).

4.9 Tillage and soil amendment effect on maize yield

Grain and biomass yield measured over two cropping seasons, major season and minor season, are presented in the Tables 4.12.

Effect of tillage on yield (biomass and grain) of maize was significantly different in both the minor and major seasons. However, maize yield were more in the major than the minor season (Table 4.12). The highest biomass and grain yield in both seasons were on the no till plots and was significantly different from H and PH plots in all seasons.

No till effect on biomass yield for the major season was 6.17%, 12.35% and 15.49% more than PP, PH and H respectively and influenced grain yield, 20.5%, 30.76% and 43.38% more than PH, PP and H tillage practices respectively.

Table 4.12. Effect of tillage on stover and grain yield (t/ha)

Tillage	Stover (t/ha)		Grain yield (t/ha)	
	Season			
	Major	**Minor**	**Major**	**Minor**
NT	8.524	7.47	4.122	0.918
H	7.208	4.08	2.334	0.571
PP	7.998	5.6	2.854	0.636
PH	7.471	3.75	3.277	0.471
Lsd (0.05)	0.818	0.801	0.5188	0.1989
CV (%)	12.6	18.4	19.8	36.8
Soil amendment				
PM	8.623	4.97	3.368	0.566
NPK	7.866	5.10	3.288	0.649
HR	6.977	6.29	3.470	0.977
NA	7.734	4.54	2.462	0.404
Lsd (0.05)	0.818	0.801	0.5029	0.1989
CV (%)	12.6	18.4	11.3	36.8

N/S = no significance, NT = no tillage, H = hoe tillage, PP = plough plant tillage, PH = Plough – harrow tillage, PM = poultry manure, NPK = NPK 15:15:15 + urea, HR = Half NPK + Half PM, NA= no amendment, Lsd = least significant difference, CV = coefficient of variation.

In the minor season, NT effect on biomass yield was 25.03%, 45% and 49.79% greater, and 30.72%, 37.79% and 48.69% more grain yield than PP, H and PH respectively (Table 4.12). Least biomass yield for the two seasons were influenced by H whereas the least grain yield was recorded under PH plots for the two seasons. There was no significant difference between PP and NT effect on biomass yield in the major season but there was significant difference between their effect on grain yield for the major season and the biomass and grain yield for the minor season.

Maize yield (grain and biomass) is affected by several factors (Table 4.12). High rainfall amounts were observed in the major rainy season than the minor season hence the lower grain and biomass yields in the minor than the major rainy season. Crop residue on the soil surface improves water infiltration, regulates soil temperature and evaporation. This could explain the higher grain and biomass yield on the NT plots (Thierfelder *et al* 2015).

Also, the crop residue improves the soils resistance to erosion and hence able to conserve more plant nutrients. Resultant effect is increased maize yield.

Dick and Gregorich (2003) assert that, uneroded soils have higher net primary productivity than eroded soils and this is so because, erosion leads soil quality reduction, soil nutrient removal and reduction in effective rooting depths of soils.

Effect of soil amendment on maize yield also showed significant differences ($P < 0.05$) and grain yield were highly variable in the minor season than the major season. Half rates of NPK and PM significantly increased maize yield than the other soil amendments. Poultry manure effect on biomass yield was the greatest while the lowest effect was recorded under HR in the major season. Highest biomass yield for the minor as well as the grain yields for the major and minor seasons were obtained on HR plots even though HR recorded the lowest biomass yield in the major season. No amendment plots recorded the lowest maize yield (biomass and grain) for the two seasons.

Chemical fertilizers rapidly releases plant nutrients and subsequently increase plant yield in the presence of soil moiture. These ready – to – use nutrients are however short lived in the soil as they are easily leached, lost through volatilization and fixed by the clay minerals in the soil reducing their availability and eventual effect on yield. Combining NPK with PM therefore sustained the nutrient needs of the maize more than the other soil amendments applied hence giving the highest crop yield. Kapkiyai *et al*. (1998) adds that, interactive effects of the integrated use of organic and inorganic plant nutrients appreciably increases crop (maize) yield.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the study, tillage practices affected soil organic carbon depending on the soil depth, soil moisture and amount of organic materials returned to the soil. Soil aggregation was also affected by soil carbon distributions within the soil depth classes.

No tillage practice increased soil organic carbon stocks in the surface (0-15) cm but not in the subsurface layer (15-30). Relative to other tillage practices, no tillage had more large macroaggregates (> 2 mm) and increased organic carbon stocks in this aggregate size in the surface layer (0-15 cm). The plough plant plots showed potentials of effective soil organic carbon protection as it contributed to higher carbon stocks within the micro aggregates (53-250 µm), and the silt and clay fractions at both depths.

In addition, because of the high carbon input on the soil surface, the No-till plots produced more carbon dioxide emissions than the conventionally tilled plots even though they recorded lower soil temperatures. Consequently a negative correlations was established between soil temperature and carbon dioxide emissions.

Poultry manure did not increase the carbon stocks of the soil as expected. The amendments applied did not significantly influence organic carbon stocks of the soil especially within the various soil aggregates and did not contribute much to carbon dioxide capture and storage within the soil.

However, poultry manure returned appreciable biomass to the soil after the major cropping season which upon decomposition would return more carbon into the soil.

Application of chemical fertilizer (NPK) increased carbon emission through accelerated humification of soil organic matter and consequently reduced carbon sequestration.

Soil structure was highly deteriorated by plough and harrow tillage whereas the other three tillage practices, No till, hoeing and plough plant significantly improved and maintained soil structure which translated into higher grain and biomass yields of maize.

The combined effect of NT/NPK and NT/PM influenced high carbon dioxide emissions and lower soil organic carbon storage within the soil aggregates whilst PP/PM showed promise of increased organic carbon storage in the aggregates and reduced carbon dioxide emissions.

No tillage increased maize yield (biomass and grain) for the two seasons but stored less organic carbon and also increased carbon dioxide emissions. Per the three pillars of sustainable agriculture, NT/PM relative to PP/PM has negative effect on environmental sustainability. Considering the effect of PP on yield of maize and its contribution to reduced soil carbon emission and increased soil organic carbon storage in the aggregates, it could be considered a better system if integrated with PM incorporation than NT/PM in terms of sustainable agriculture.

5.2 Recommendations

From this study, the following recommendations have been made:

1. Plant biomass be incorporated into the soil rather than on the soil surface and the use of deep plough plant or plough and harrowing be reduced to avoid loss of soil structure and organic matter.
2. Integration of poultry manure and ploughing can reduce carbon dioxide emission and protect soil organic carbon within soil aggregates. However, there should be further studies as to the time for poultry manure application with ploughing.
3. Soil carbon dioxide emission study was carried out during the dry cropping season without irrigation and so it is recommended that rainy season measurement be done and also longer period studies of tillage practices with carbon dynamics be carried out.

REFERENCES

Ahn, P. M., and Hintze, B. (1990). No tillage, minimum tillage, and their influence on soil properties. Organic-matter Management and Tillage in Humid and Sub-humid Africa, 341-349.

Al-Kaisi, M. M., and Yin, X. H. (2005) Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn-soybean rotations J. Environ. Qual. 34: 37- 45

Al-Kaisi, M. M., Kruse, M. L. and Sawyer, J. E. (2008). Effect of nitrogen fertilizer application on growing season carbon dioxide emission in a corn-soybean rotation. J. Environ. Qual. 37: 325-332.

Almaraz, J. J., Mabood, F., Zhou, X., Madramootoo, C., Rochette, P., Ma, B. L., and Smith. D. L (2009). Carbon dioxide and nitrous oxide fluxes in corn grown under two tillage systems in southwestern Quebec. Soil Science Society of America Journal 73: 113–119.

Alvarez, R., Alvarez, C. R., and Lorenzo, G. (2001). Carbon dioxide fluxes following tillage from a mollisol in the Argentine rolling Pampa. Eur. J. Soil Biol. 371: 1–6

Alvarez, R., Russo, M. E., Prystupa, P., Scheiner, J. D., and Blotta, L. (1998). Soil carbon pools under conventional and no-tillage systems in the Argentine Rolling Pampa. Agric. J. 90: 138–143.

Anderson, J., and Ingram, J. (1993). Tropical soil biology and fertility (TSBF).Handbook of Methods. CAB. Internacional. 171p.

Angers, D. A. and Chenu, C. (1998). Dynamics of soil aggregation and C sequestration. In: Soil Processes and the Carbon Cycle. pp. 199–206. Lal, R., Kimble, J. M., Follet, R. F., and Stewart B. A., Eds., CRC Press, Boca Raton, FL.

Angers, D. A. and Giroux, M. (1996). Recently deposited organic matter in soil water-stable aggregates. Soil Sci. Soc. Am. J. 60: 1547–1551.

Angers, D. A., and Eriksen-Hamel, N. S. (2008). Full-inversion tillage and organic carbon distribution in soil profiles: a meta-analysis. Soil Science Society of America Journal, 72: 1370-1374.

Aslam, T., Choudhary, M. A. and Saggar, S., (2000). Influence of land-use management on CO2 emissions from a silt loam soil in New Zealand. Agric. Eco: Enviro. 77: 257-262.

Baker, J. M., Ochsner, T. E., Venterea, R. T., and Griffis, T.J. (2007). Tillage and soil carbon sequestration – what do we really know? Agr. Ecosyst. Environ. 118: 1–5.

Baldock J. (2008). Factors which influence soil carbon levels. Fast facts. CSIRO.

Ball, B. C., Scott, A., and Parker, J. P. (1999). Field N_2O, CO_2 and CH_4 fluxes in relation to tillage, compaction and soil quality in Scotland. Soil and Tillage Research, 53: 29-39.

Batjes, N. H. (1996). Total carbon and nitrogen in the soils of the world. Eur. J. Soil Sci. 47: 151–163.

Bauer, P. J., Frederick, J. R., Novak, J. M., and Hunt, P. G. (2006). Soil CO_2 flux from a Norfolk loamy sand after 25 years of conventional and conservation tillage. Soil and Tillage Research, 90: 205-211.

Beare, M. H., Hendrix, P. F., and Coleman, D. C. (1994a).Water-stable aggregates and organic matter fractions in conventional- and no-tillage soils. Soil Sci. Soc. Am. J. 58: 777–786.

Bertrand, B., O. Delfose, and B. Mary. (2007). Carbon and nitrogen mineralization in acidic, limed and calcareous agricultural soils: Apparent and actual effects. Soil Biol. Biochem. 39: 276–288.

Beyer, L. (1991). Inter-site characterization and variability of soil respiration in different arable and forest soils. Biol. Fertil. Soils 12: 122–126.

Blanco-Canqui, H., and Lal, R. (2004) Mechanisms of Carbon Sequestration in Soil Aggregates, Critical Reviews in Plant Sciences, 23: 481-504,

Bossuyt, H., Six, J., and Hendrix, P. F. (2002). Aggregate-protected carbon in no-tillage and conventional tillage agroecosystems using carbon-14 labelled plant residue, Soil Sci. Soc. Am. J. 66: 1965–1973.

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

Bronick, C. J., and Lal, R. (2005). Manuring and rotation effects on soil organic carbon concentration for different aggregate size fractions on two soils in north-eastern Ohio, USA. Soil and Tillage Research, 81: 239-252.

Buyanovsky, G. A., Wagner, G. H., and Gantzer, C. J., (1986). Soil respiration in a winter wheat ecosystem. Soil Sci. Soc. Am. J. 50: 338–344.

Cambardella, C. A., and Elliot, E. T. (1993). Carbon and nitrogen distribution in aggregate from cultivated and native grassland soils. Soil Sci. Soc. Am. J. 57: 1071–1076.

Chatskikh, D., and Olesen, J. (2007). Soil tillage enhanced CO_2 and N_2O emissions from loamy sand soil under spring barley. Soil and Tillage Research, 97: 5-18.

Chatskikh, D., Olesen, J., Hansen, E. M., Elsgaard, L., and Peterse, B. M. (2008). Effects of reduced tillage on net greenhouse gas fluxes from loamy sand soil under winter crops in Denmark. Agriculture, Ecosystems and Environment, 128: 117-126.

Chenu, C., and Guerif, J. (1991). Mechanical strength of clay minerals as influenced by an adsorbed polysaccharide. Soil Sci. Soc. Am. J. 55: 1076–1080.

Conservation Tillage Information Center (CTIC). (2002). Tillage type definitions. http://www.ctic.purdue. edu/core4/CT/Definitions.html

Curtin, D., Wang, H., Selles, F., McConkey, B.G., and Campbell. C. A. (2000). Tillage effects on carbon fluxes in continuous wheat and fallow-wheat rotations. Soil Sci. Soc. Am. J. 64: 2080-2086.

Denef, K., Six, J., Paustian, K., and Merckx, R. (2001). Importance of macroaggregate dynamics in controlling soil carbon stabilization: short-term effects of physical disturbance induced by dry–wet cycles. Soil Biology and Biochemistry, 33(15), 2145-2153.

Dick, W. A., and Gregorich, E. G. (2003). Developing and maintaining soil organic matter levels. Managing soil quality: challenges in modern agriculture, 103-120.

Ding, W., Meng, L., Yin, Y., Cai, Z., and Zheng, X. (2007). CO_2 emission in an intensively cultivated loam as affected by long term application of organic manure and nitrogen fertilizer. Soil Biol. Biochem. 39: 669–679.

Edwards, A. P., and Bremner, J. M. (1967). Microaggregates in soils. J. Soil Sci. 18: 65–73.

Edwards, J.H., Wood, C.W., Thurlow, D.L., and Ruf M.E. (1999). Tillage and crop rotation effects on fertility status of a Hapludalf soil. Soil Sci. Soc. Am. J. 56: 1577-1582.

Edwards, N.T. (1982). The use of soda-lime for measuring respiration rates in terrestrial systems. Pedobiologia 23: 321–330.

Elder, J.W., and Lal, R. (2008). Tillage effects on gaseous emissions from an intensively farmed organic soil in North Central Ohio. Soil and Tillage Research, 98: 45-55.

Ellert, B. H., and Janzen, H.H. (1999). Short-term influence of tillage on CO_2 fluxes from a semi-arid soil on Canadian Prairies. Soil Tillage Research, 50(1), 21-32.

Eswaran, H., Van den Berg, E., Reich, P., and Kimble, J. (1995). Global soil carbon resources. In: Lal R, Kimble JM, Levine E, Stewart BA, editors. Soils and global change. Boca Raton: CRC/Lewis. 27–43.

Fabrizzi, K. P., Garcıa, F. O., Costa, J. L., and Picone, L. I. (2005). Soil water dynamics, physical properties and corn and wheat responses to minimum and no-tillage systems in the southern Pampas of Argentina. Soil and Tillage Research, 81(1), 57-69.

FAO, (2012). Crop water information. Sugar beet. Available at: http://www.fao.org/nr/water/cropinfo_sugarbeet.html.

Feiziene, D., Feiza, V., Kadziene, G., Vaideliene, A., Povilaitis, V., and Deveikyte, I. (2012). CO2 fluxes and drivers as affected by soil type, tillage and fertilization. Acta Agriculturae Scandinavica, Section B-Soil & Plant Science, 62(4), 311-328.

Fernandez, I. J., Son, Y. W., Kraske, C. R., Rustad, L. E., and David, M. B., (1993). Soil carbon dioxide characteristics under different forest types and after harvest. Soil Sci. Soc. Am. J. 57: 1115–1121.

Follett, R.F. (2001). Soil management concepts and carbon sequestration in cropland soils. Soil Tillage Res. 61: 77–92.

Fortin, M. C., Rochette, P., and Pattey, E. (1996). Soil carbon dioxide fluxes from conventional and no-tillage small-grain cropping systems. Soil Sci. Soc. Am. J. 60: 1541-1547.

Frank, A. B., Liebig, M. A., and Hanson, J. D. (2002). Soil carbon dioxide fluxes in northern semiarid grasslands. Soil Biology & Biochemistry 34: 1235–1241.

Franzluebbers, A. J. (2005). Soil organic carbon sequestration and agricultural greenhouse gas emissions in the south-eastern USA. Soil Till. Res. 83: 120–147.

Franzluebbers, A. J.(2004). Tillage and residue management effects on soil organic matter. In: Magdoff, F., and Weil, R. R. (eds), Soil organic matter in sustainable agriculture, CRC Press, Boca Raton, Florida, 227-268

Franzluebbers, A. J., and Arshad, M. A. (1997). Soil microbial biomass and mineralizable carbon of water-stable aggregates. Soil Sci. Soc. Am. J. 61: 1090–1097.

Franzluebbers, A. J., and Follett, R. F. (2005). Greenhouse gas contributions and mitigation potential in agricultural regions of North America: Introduction. Soil and Tillage Research, 83(1), 1-8.

Franzluebbers, A. J., Hons, F. M., and Zuberer, D. A. (1995). Tillage-induced seasonal changes in soil physical properties affecting CO2 evolution under intensive cropping. Soil Till. Res. 34: 41–60.

Franzluebbers, A. J., Langdale, G.W., and Schomberg, H. H. (1999). Soil carbon, nitrogen, and aggregation in response to type and frequency of tillage. Soil Sci. Soc. Am. J. 63: 349–355.

Franzluebbers, A. J., Wright, S. F., and Stuedemann, J. A. (2000). Soil aggregation and glomalin under pastures in southern Piedmont USA. Soil Sci. Soc. Am. J. 64: 1018–1026.

Gál, A., Vyn, T. J. Michéli, E., Kladivko, E. J., and McFee, W. W. (2007). Soil carbon and nitrogen accumulation with long-term no-till versus mouldboard ploughing overestimated with tilled-zone sampling depths. Soil Tillage Res. 96: 42–51

Gale, W. J., and Cambardella, C. A. (2000). Carbon dynamics of surface residue–and root-derived organic matter under simulated no-till. Soil Science Society of America Journal, 64(1), 190-195.

Gale, W. J., Cambardella, C. A., and Bailey, T. B. (2000). Root-derived carbon and the formation and stabilization of aggregates. Soil Sci. Soc. Am. J. 64: 201-207.

Golchin, A., Oades, J. M., Skjemstad, J. O., and Clark, P. (1994). Soil structure and carbon cycling. Aust. J. Soil Res. 32: 1043–1068.

Govaerts, B., Mezzalama, M., Sayre, K. D., Crossa, J., Lichter, K., Troch, V., Vanherck, K., De Corte, P., and Decker, J. (2008). Long-term consequences of tillage, residue management, and crop rotation on selected soil micro-flora groups in the subtropical highlands. Applied Soil Ecology 38: 197–210.

Greenland, D. J. (1965). Interactions between clays and organic compounds in soils. Part II. Adsorption of soil organic compounds and its effect on soil properties. Soils and Fert. 28: 521–527.

Guo, J. (2014). The Influence of Tall Fescue Cultivar and Endophyte Status on Root Exudate Chemistry and Rhizosphere Processes.

Hadas, A., Agassi, M., Zhevelev, H., Kautsky, L., Levy, G. J., Fizik, E., and Gotessman, M. (2004). Mulching with composted municipal solid wastes in the Central Negev, Israel. II. Effect on available nitrogen and phosphorus and on organic matter in soil. Soil Tillage Res. 78: 115–128.

Hadas, A., Parkin, T. B., and Stahl, P. D. (1998). Reduced CO_2 release from decomposing wheat straw under N-limiting conditions: Simulation of carbon turnover. Eur. J. Soil Sci. 49: 487–494.

Haney, R. L., Brinton, W. H., and Evans, E. (2008). Estimating soil carbon, nitrogen and phosphorus mineralization from short-term carbon dioxide respiration. Communications in Soil Science and Plant Analysis, 39 (17-18) 2706-2720.

Hansen, S., Jensen, H. E., Nielsen, N. E., and Svendsen, H. (1991). Simulation of nitrogen dynamics and biomass production in winter wheat using the Danish simulation model DAISY. Fertilizer Research 27: 245–259.

Hati, K. M., Mandal, K. G., Misra, A. K., Ghosh, P. K., and Bandyopadhyay, K. K. (2006). Effect of inorganic fertilizer and farmyard manure on soil physical properties, root distribution, and water-use efficiency of soybean in Vertisols of central India. Bioresource Technology, 97: 2182-2188.

Haynes, B. E., and Gower, S. T. (1995). Belowground carbon allocation in unfertilized Red pine plantations in Northern Wisconsin. Tree Physiology 15, 317–325.

Heller, H., Bar-Tal, A., Tamir, G., Bloom, P., Venterea, R. T., Chen, D., Zhang, Y., Clapp, E. C., and Fine, P. (2010). Effects of Manure and Cultivation on Carbon Dioxide and Nitrous Oxide Emissions from a Corn Field under Mediterranean Conditions. Technical reports: atmospheric pollutants and trace gases. J. Environ. Qual. 39: 437–448

Hendrix, P. F., Han, C. R., and Groffman, P. M., (1988). Soil respiration in conventional and no-tillage agroecosystems under different winter cover crop rotations. Soil Till. Res. 12: 135–148.

Hermle, S., Anken, T., Leifeld, J., and Weisskopf, P. (2008). The effect of the tillage system on soil organic carbon content under moist, cold-temperate conditions. Soil Tillage Res. 98:94–105.

Hillel, D. (1998). Environmental soil physics: Fundamentals, applications, and environmental considerations. Academic press.

Insam, H., and Domsch, K.H. (1989). Relationship between soil organic carbon and microbial biomass on chronosequence of reclamation sites. Microbial Ecology 15: 177–188.

IPCC (Inter-governmental Panel on Climate Change) (1995). Second assessment: climate change 1995. A report of the Intergovernmental Panel on Climate Change. Geneva and Nairobi: World Meteorological Organization and United Nations Environment Programme.

IPCC (Intergovernmental Panel on Climate Change) (2000). Land Use, Land Use Change and Forestry. Special Report, Cambridge Univ. Press, Cambridge, U.K.

IPCC (Inter-governmental Panel on Climate Change) (2003). Good Practice Guidance for Greenhouse Gas Inventories for Land-Use, Land-Use Change & Forestry. Institute of Global Environmental Strategies (IGES), Kanagawa, Japan.

IPCC (Inter-governmental Panel on Climate Change) (2006). Agriculture, forestry and other land use. In: Eggleston H. S., Buendia L., Miwa K., Ngara T., Tanabe K. (Eds.), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, vol. 4. IGES, Japan.

IPCC (Inter-governmental Panel on Climate Change) (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. In: Parry, M.L, Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Jacinthe, P. A., and Lal, R. (2005). Labile carbon and methane uptake as affected by tillage intensity in a Mollisol. Soil and Tillage Research, 80(1), 35-45

Janssens, I. A., and Ceulemans, R. (1998). Spatial variability in forest soil CO2 efflux assessed with a calibrated soda lime technique. Ecological Letters 1: 95–98.

Janssens, I. A., Kowalski, A. S., Longdoz, B., and Ceulemans, R., (2000). Assessing forest soil CO_2 efflux: an in situ comparison of four techniques. Tree Physiology 20: 23–32.

Jarecki, M. K., Lal, R., and James, R. 2005. Crop management effects on soil carbon sequestration on selected farmers' fields in north-eastern Ohio. Soil Till. Res. 81: 265-276.

Jastrow, J. D., Miller,R. M., and Lussenhop, J. (1998). Contributions of interacting biological mechanisms to soil aggregate stabilization in restored prairie. Soil Biol. Biochem. 30: 905–916.

Jensen, L. S., Mueller, T., Tate, K. R., Riss, D. J., Magid, J. and Nielsen, N. E., (1996). Soil Biol. Biochem., 28: 1297–1306

Jinyan, Y., and Chuankuan, W. (2006). Partitioning soil respiration of temperate forest ecosystems in north-eastern China. Acta Ecologica Sinica 26: 1640–1647.

Johnson, J. M. F., Franzluebbers, A. J., Lachnicht, S. W., and Reicosky, D.C. (2007). Agricultural opportunities to mitigate greenhouse gas emissions. Environ. Pollut. 150: 107–124.

Johnson, J. M. F., Reicosky, D. C., Allmaras, R. R., Sauer, T. J., Venterea, R. T., and Dell, C. J. (2005). Greenhouse gas contributions and mitigation potential of agriculture in the central USA. Soil Till. Res. 83: 73–94.

Johnson, J. M., Archer, D., and Barbour, N. (2010). Greenhouse gas emission from contrasting management scenarios in the northern Corn Belt. Soil Science Society of America Journal, 74(2), 396-406.

Jones, S. K., Rees, R. M., Skiba, U. M., and Ball, B. C. (2005). Greenhouse gas emissions from a managed grassland. Global Planet. Change 47: 201–211.

Kaiser, K., and Guggenberger, G. (2003). Mineral surfaces and soil organic matter. European Journal of Soil Science, 54(2), 219-236.

Kapkiyai, J. J., Karanja, N. K., Woomer, P. L., and Qureshi, J. N. (1998). Soil organic carbon fractions in a long-term experiment and the potential for their use as a diagnostic assay in highland farming systems of central Kenya highlands.

Kätterer, T., Bolinder, M. A., Berglund, K., and H. Kirchmann (2012) Strategies for carbon sequestration in agricultural soils in northern Europe, Acta Agriculturae Scandinavica, Section A — Animal Science, 62:4, 181-198

Keith, H., and Wong, S. C. (2006). Measurement of soil CO_2 efflux using soda lime absorption:both quantitative and reliable. Soil Biology & Biochemistry 38: 1121–1131.

Kemper, W. D., and Rosenau, R. C. (1986). Aggregate stability and size distributions. In: Methods of Soil Analysis. Part 1. 2nd ed. A. Klute (ed.). Agron. Monogr. 9. ASA and SSSA, Madison, WI, pp. 425-442.

Kessavalou, A., Doran, J. W., Mosier, A. R., and Drijber, R. A., (1998a). Greenhouse gas fluxes following tillage and wetting in a wheat-fallow cropping system. J. Environ. Qual. 27: 1105–1116.

Kessavalou, A., Mosier, A. R., and Doran, J. W. (1998b). Fluxes of carbon dioxide, nitrous oxide, and methane in grass sod and winter wheat-fallow tillage management. J. Environ. Qual. 27: 1094–1104.

Kjeldahl, J. G. C. T. (1884). Neue methode zur bestimmung des stickstoffs in organischen körpern. Fresenius' Journal of Analytical Chemistry, 22(1), 366-382

Kong, A. Y., Six, J., Bryant, D. C., Denison, R. F., and Van Kessel, C. (2005). The relationship between carbon input, aggregation, and soil organic carbon stabilization in sustainable cropping systems. *Soil Science Society of America Journal*, *69*(4), 1078-1085.

Kumar, S., Kadono, A., Lal, R., and Dick, W. (2012). Long-term no-till impacts on organic carbon and properties of two contrasting soils and corn yields in Ohio. Soil Sci. Soc. Am. J. 76: 798–809.

La Scala, N., Bolonhezi, D., and Pereira, G. T. (2006). Short-term soil CO_2 emission after conventional and reduced tillage of a no-till sugar cane area in southern Brazil. Soil Till. Res. 91: 244–248.

Laird, D. A. (2001). Nature of clay-humic complexes in an agricultural soil: II. Scanning electron microscopy analysis. Soil Sci. Soc. Am. J. 65: 1419–1425.

Lal, R. (1983). Soil erosion in the humid tropics with particular reference to agricultural land development and soil management. Int. Assoc. Hydrol. Sci. Publ 140, 221-239.

Lal, R. (1995). Global soil erosion by water and carbon dynamics. In: Lal, R., Kimble, J.M., Levine, E., Stewart, B.A. (Eds.), Soils and Global Change. CRC/Lewis Publishers, Boca Raton, FL, pp. 131 – 142.

Lal, R. (1996). Deforestation and land use effects on soil degradation and rehabilitation in western Nigeria. II. Soil chemical properties. Land Degrad. Dev. 7: 87 – 98.

Lal, R. (1997). Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO 2-enrichment. Soil and Tillage Research, 43(1), 81-107.

Lal, R. (1998). No-till and mulching effects on soil physical quality of a tropical Alfisol in western Nigeria. Soil Quality and Agricultural Sustainability. Ann Arbor Press, Chelsea, MI, 251-265.

Lal, R. (2002a). Soil carbon dynamics in cropland and rangeland. Environ. Pollut. 116: 353–362.

Lal, R. (2002b): Carbon sequestration in dry ecosystems of West Asia and North Africa. Land Degradation and Management, 13: 45-59.

Lal, R. (2002c). Why carbon sequestration in soils. In: Agricultural Practices and Policies for Carbon Sequestration in Soil. pp, 21–30. Kimble, J. M. et al., Eds., CRC Press, Boca Raton, FL.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Sci. 304: 1623–1627.

Lal, R. (2008) Soils and sustainable agriculture. A review, Agron. Sustain. Dev. 28: 57–64.

Lal, R. (2009). Challenges and opportunities in soil organic matter research. Eur. J. Soil Sci. 60: 1–12.

Lal, R., and Kimble, J. M. (1997). Conservation tillage for carbon sequestration.Nutrient cycling in agroecosystems, 49(1-3), 243-253.

Lal, R., Kimble, J. M., Follett, R. F., and Cole, C. V. (1998). The Potential for US Cropland to Sequester Carbon and Mitigate the Greenhouse Effect (Eds.). Ann Arbor Science, Chelsea MI.

Le Dantec, V., Epron, D., and Dufrene, E., (1999). Soil CO2 efflux in a beech forest: comparison of two closed dynamic systems. Plant & Soil 214, 125–132.

Lee, D. K., Doolittle, J. J., and Owens, V. N. (2007). Soil carbon dioxide fluxes in established switch grass land managed for biomass production. Soil Biology & Biochemistry 39: 178–186.

Lee, J., Hopmans, J.W., Rolston, D.E., Baer, S.G., and Six, J. (2009). Determining soil carbon stock changes: simple bulk density corrections fail. Agric. Ecosyst. Environ. 134: 251–256.

Leirós, M. C., Trasar-Cepeda, C., Seoane, S., and Gil-Sotres, F. (2000). Biochemical properties of acid soils under climax vegetation (Atlantic Oakwood) in an area of the European temperate–humid zone (Galicia, NW Spain): general parameters. Soil Biology and Biochemistry, 32(6), 733-745.

Leu A. (2007). Organics and Soil Carbon: Increasing soil carbon, crop productivity and farm profitability Managing the Carbon Cycle' Kittanning Workshop 21-22

Liebig, M. A., Morgan, J. A., Reeder, J. D., Ellert, B.H., Gollany, H.T., and Schuman, G.E. (2005). Greenhouse gas contributions and mitigation potential of agricultural practices in north-western USA and western Canada. Soil Tillage Res. 83: 25–52.

Lorenz, K., and Lal, R. (2005). The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons. Advances in agronomy, 88, 35-66.

Lund, C.P., Riley, W. J., Pierce, L. L., and Field, C. B., (1999). The effects of chamber pressurization on soil-surface CO_2 flux and the implications for NEE measurements under elevated CO_2. Global Change Biology 5: 269–281.

Lundegård, H. (1927). Carbon dioxide evolution of soil and crop growth. Soil Science, 23: 417-453

Luo, Z., Wang E., and Sun, O.J. (2010). Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. Agric. Ecosyst. Environ. 139: 224–231.

Lupwayi, N. Z., Rice, W. A., and Clayton, G. W. (1998). Soil microbial diversity and community structure under wheat as influenced by tillage and crop rotation.Soil Biology and Biochemistry, 30(13), 1733-1741.

Madejón, E., Murillo, J. M., Moreno, F., López, M. V., Arrue, J. L., Alvaro-Fuentes, J., and Cantero, C. (2009). Effect of long-term conservation tillage on soil biochemical properties in Mediterranean Spanish areas. Soil and Tillage Research, 105(1), 55-62.

Maguire, R. O., Edwards, A. C., and Wilson, M. J. (1998). Influence of cultivation on the distribution of phosphorus in three soils from NE Scotland and their aggregate size fractions. Soil Use Manage. 14: 147–153.

Martens, D. A. (2000). Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. Soil Biol. Biochem. 32: 361–369.

Matthews, R.B., and Pilbeam, C. (2005). Modelling the long-term productivity and soil fertility of maize/millet cropping systems in the mid-hills of Nepal. Agricul. Ecosys. Env. 111: 119–139.

McConkey, B. G., Liang, B. C., Campbell, C. A., Curtin, D., Moulin, A., Brandt S. A., and Lafond, G. P. (2003). Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. Soil Tillage Res. 74: 81–90.

McLain, J. E., and Martens, D. A. (2006). Moisture controls on trace gas fluxes in semiarid riparian soils. Soil Science Society of America Journal, 70: 367-377.

Mendes, I. C., Mandick, A. K., Dick, R. P., and Bottomley, P. J. (1999). Microbial biomass and activities in soil aggregates affected by winter cover crops. Soil Sci. Soc. Am. J. 63: 873–881.

Mielnick, P. C., and W. A. Dugas. (2000). Soil CO_2 flux in a tallgrass prairie. Soil Biology & Biochemistry 32: 221–228.

Miller, M., and Dick, R. P. (1995). Dynamics of soil carbon and microbial biomass in whole-soil and aggregates in two cropping systems. Appl. Soil Ecol. 2: 253–261.

Milne, E., and Heimsath, A. (2009). Soil organic carbon. Encyclopedia of Earth. http://www. eoearth. Org/article/Soil_organic_carbon (accessed 2 Feb. 2011).

Mohammadi, K., Sohrabi, Y., Heidari, G., Khalesro, S. and Majidi, M. (2012). Effective factors on biological nitrogen fixation. African Journal of Agricultural Research 7(12):1782-1788.

Morari, F., Lugato, E., Berti, A., and Giardini, L. (2006). Long-term effects of recommended management practices on soil carbon changes and sequestration in north-eastern Italy. Soil Use Mgt. 22: 71–81.

Murphy, G. (2005). Ontario-Ministry of Agriculture, Food and Rural affairs, Resistance Management-Pesticide Rotation

Nay, S. M., Mattson, K. M., and Bormann, B. T., (1994). Biases of chamber methods for measuring soil CO2 efflux demonstrated with a laboratory apparatus. Ecology 75: 2460–2463.

Nobuhisa, K., and Hiroyuki, T. (2009) Effects of reduced tillage, crop residue management and manure application practices on crop yields and soil carbon sequestration on an Andisol in northern Japan, Soil Science and Plant Nutrition, 55: 546-557

Norman, J. M., Kucharik, C. J., Gower, S. T., Baldocchi, D. D., Crill, P. M., Rayment, M., Savage, K., and Striegl, R. G. (1997). A comparison of six methods for measuring soil-surface carbon dioxide fluxes. Journal Geophysical Research 102: 771–777.

Nyakatawa, E. Z., Reddy, K. C., and Lemunyon, J. L. (2001a). Predicting soil erosion in conservation tillage cotton production systems using the Revised Universal Soil Loss Equation (RUSLE). Soil & Tillage Research 57: 213–224.

Nyakatawa, E. Z., Reddy, K. C., and Sistani, K. R. (2001b). Tillage, cover cropping, and poultry litter effects on selected soil chemical properties. Soil & Tillage Research 58: 69–79.

Nyakatawa, E.Z., Mays, D. A., Way, T. R., Watts, D. B., Torbert, H. A., and Smith D. R. (2012) Soil Carbon Dioxide Fluxes in Conventional and Conservation Tillage Corn Production Systems Receiving Poultry Litter and Inorganic Fertilizer, Journal of Sustainable Agriculture, 36: 873-892,

OECD (1999) Environmental Indicators for Agriculture. Issues and Design, The York Workshop, Vol. 2. OECD, Paris.

Ogle, S. M., Swan, A., and Paustian, K. (2012). No-till management impacts on crop productivity, carbon input and soil carbon sequestration. Agric Ecosyst Environ. 149: 37-49.

Oladipo, O. G., Olayinka, A., Aladesanmi, O. T., Sanni, M., Famurewa A. J. and Siyanbola, W. O., (2010). Risk mitigation strategies and policy implications for carbon dioxide (CO_2) emission in organically- amended soils in Nigeria. African Journal of Environmental Science and Technology Vol. 4: 801-806

Olson, K. R. (2010). Impacts of tillage, slope and erosion on soil organic carbon retention. Soil Sci. 175: 562-567.

Olson, K. R., Al-kaisi, M. M., Lal, R., and Lowery, B. (2014). Experimental consideration, treatments, and methods: In determining soil organic carbon sequestration rates. Soil Sci. Soc. Am. J. 78:348–360

Omonode, R. A., Vyn, T. J., Smith, D. R., Hegymegi, P., and Gal, A., (2007). Soil carbon dioxide and methane fluxes from long-term tillage systems in continuous corn and corn–soybean rotations. Soil Till. Res. 95, 182–195.

Oorts, K., Merckx, R., Gr´ehan, E., Labreuche, J., and Nicolardot, B. (2007). Determinants of annual fluxes of CO2 and N2O in long-term no-tillage and conventional tillage systems in northern France. Soil Till. Res. 95: 133–148.

Osozawa, S., and Hasegawa, S. (1995). Diel and seasonal changes in carbon dioxide concentration and flux in an Andisol. Soil Science, 160(2), 117

Page, A.L., Miller, R.H. and Keeney, D.R. (1982) (eds.). Methods of soil analysis. Part 2. Second edition. Chemical and microbiological properties. American Society of Agronomy and Soil Science Society of America. Madison, Wisconsin USA. pp. 301-312.

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S. and Hayes, D. (2011). A large and persistent carbon sink in the world's forests. Science, 333: 988-993.

Paustian, K. A. O. J. H., Andrén, O., Janzen, H. H., Lal, R., Smith, P., Tian, G., Tiessen, H., Van Noordwijk, M., and Woomer, P. L. (1997). Agricultural soils as a sink to mitigate CO2 emissions. Soil use and management, 13(s4), 230-244.

Perfect, E., Kay, B. D., van Loon, W. K. P., Sheard, R. W., and Pojasok, T. (1990). Factors influencing soil structural stability within a growing season. Soil Sci. Soc. Am. J. 54: 173–179.

Pieri, C., 1991. Fertility of Soils: A Future for Farming in the West African Savannah. Springer-Verlag, Berlin.

Plaza-Bonilla, D., Cantero-Martínez, C., Viñas, P., and Álvaro-Fuentes, J. (2013). Soil aggregation and organic carbon protection in a no-tillage chronosequence under Mediterranean conditions. Geoderma, 193, 76-82.

Poirier, V., Angers, D. A., Rochette, P., Chantigny, M. H., Ziadi, N., Tremblay, G., and Fortin, J. (2009). Interactive effects of tillage and mineral fertilization on soil carbon profiles. Soil Science Society of America Journal, 73(1), 255-261.

Prior, S. A., Reicosky, D. C., Reeves, D. W., Runion, G. B., and Raper, R. L. (2000). Residue and tillage effects on planting implement-induced short-term CO2 and water loss from a loamy sand soil in Alabama. Soil Till. Res. 54: 197-199.

Puget, P., Chenu, C., and Balesdent. J. (1995). Total and young organic matter distributions in aggregates of silty cultivated soils. Eur. J. Soil Sci. 46: 449–459.

Pumpanen, J., Kolari, P., Ilvesniemi, H., Minkkinen, K., Vesala, T., Niinistö, S., and Hari, P. (2004). Comparison of different chamber techniques for measuring soil CO_2 efflux. Agricultural and Forest Meteorology, 123(3), 159-176.

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

Raich, J. W., Bowden, R. D., and Steudler, P.A., (1990). Comparison of two static chamber techniques for determining carbon dioxide efflux from forest soils. Soil Sci. Soc. Am. J. 54: 1754–1757.

Rasmussen, P. E., and Parton, W. J. (1994). Long-term effects of residue management in wheat-fallow: I. Inputs, yield and soil organic matter. Soil Sci. Soc. Am. J. 58: 523–530.

Rasmussen, P. E., Goulding, K.W.T., Brown, J.R., Grace, P.R., Janzen, H.H., and Körschens, M. (1998). Long term agro ecosystems experiments: assessing agricultural sustainability and global change. Science 282: 893–896.

Rasse, D. P., Dignac, M. F., Bahri, H., Rumpel, C., Mariotti, A., and Chenu, C. (2006). Lignin turnover in an agricultural field: from plant residues to soil-protected fractions. European Journal of Soil Science, 57(4), 530-538.

Rastogi, M., Singh, S., and Pathak, H. (2002). Emission of carbon dioxide from soil. Current science, 82(5), 510-517

Reicosky, D. C., and Lindstrom, M. J. (1993). Fall tillage method: effect on short-term carbon dioxide flux from soil. Agronomy Journal, 85(6), 1237-1243.

Reicosky, D. C., Dugas, W. A., and Torbert, H. A. (1997). Tillage induced soil carbon dioxide loss from different cropping systems. Soil Till. Res. 41: 105-118.

Reicosky, D. C., Lindstrom, M. J., Schumacher, T. E., Lobb, D. E., and Malo, D. D. (2005). Tillage-induced CO2 loss across an eroded landscape. Soil and Tillage Research, 81: 183-194.

Resck, D. V. S., Vasconcellos, C. A., Vilela, L., and Macedo, M. C. M. (1999). Impact of conversion of Brazilian Cerrados to cropland and pastureland on soil carbon pool and dynamics. Global Climate Change and Tropical Ecosystems. Adv. Soil Sciences. CRC Press, Boca Raton, FL, 169-196.

Reth, S., M., Reichstein, and E. Falge. (2005). The effect of soil water content, soil temperature, soil pH-value and the root mass on soil CO2 efflux – A modified model. Plant and Soil 268: 21–33.

Rey, A, E., Pegoraro, V., Tedeschi, I., De Parri, P. G., Jarvis, and R. Valentini. (2002). Annual variation in soil respiration and its components in a coppice oak forest in central Italy. Global Change Biology 8: 851–866.

Robertson, G. P. (2008) Sustainable biofuels redux. Science 322:49–50

Rochette, P., and Hutchinson, G. L. (2005). Measurement of soil respiration in situ: chamber techniques. In: Hatfield J.L., Baker J.M. (Eds.), Micrometeorology in Agricultural Systems ASA-CSSA-SSSA. Agron. Monogr. 47: 247–286.

Rochette, P., Angers, D. A., Chantigny, M. H., Bertrand, N., and Cote, D. (2004). Carbon dioxide and nitrous oxide emissions following fall and spring applications of pig slurry to an agricultural soil. Soil Science Society of America Journal 68: 1410–1420.

Rochette, P., Flanagen, L. B., and Gregorich, E. G. (1999). Separating soil respiration into plant and soil components using analysis of the natural abundance of carbon-13. Soil Sci. Soc. Am. J. 63: 1207–1213.

Rochette, P., Gregorich, E.G., and Desjardins, R.L., (1992). Comparison of static and dynamic closed chambers for measurement of soil respiration under field conditions. Canadian Journal of Soil Science 72: 605–609.

Ruddiman, W. F. (2007). The early anthropogenic hypothesis: Chanllenges and resonses. Reviews of Geophysics, 45 (4).

Rudrappa, L., Purakayasha, T. J., Singh, D., and Bhadraray, S. (2006). Long-term manuring and fertilization effects on soil organic carbon pools in a Typic Haplustept of semi-arid sub-tropical India. Soil Till. Res. 88: 180–192.

Rustad, L. E., Huntington, T. G., and Boone, R. D. (2000). Controls on soil respiration: implications for climate change. Biochemistry 48: 1–6.

Sainju, U. M. (2006). Carbon and nitrogen pools in soil aggregates separated by dry and wet sieving methods. Soil science, 171: 937-949.

Salam, M. A., Alam, M. K., and Rashid, M. H. (2013). Effects of different tillage practices and cropping patterns on soil physical properties and crop productivity. Journal of Tropical Resources and Sustainable Sciences, 1: 51-61.

Salem, H. M., Valero, C., Muñoz, M. Á., Rodríguez, M. G., and Silva, L. L. (2015). Short-term effects of four tillage practices on soil physical properties, soil water potential, and maize yield. Geoderma, 237, 60-70.

Santos, D., Smucker, A. J. M., Murphy, S. L. S., Taubner, H., and Horn, R. (1997). Uniform separation of concentric surface layers from soil aggregates.Soil Science Society of America Journal, 61(3), 720-724.

Sarkar, S., Singh, S. R., and Singh, R. P. (2003). The effect of organic and inorganic fertilizers on soil physical condition and the productivity of a rice–lentil cropping sequence in India. The Journal of Agricultural Science, 140(04), 419-425.

Schimel, D. S. (1995). Terrestrial ecosystems and the carbon cycle. Global Change Biol. 1: 77– 91.

Schlesinger, W. H. (1999). Carbon and agriculture: Carbon sequestration in soils. Science 284: 20-95.

Schutter, M. E., and Dick, R. P. (2002). Microbial community profiles and activities among aggregates of winter fallow and cover-cropped soil. Soil Sci. Soc. Am. J. 66: 142–153.

Seech, A. G., and E. G. Beauchamp. (1988). Denitrification in soil aggregates of different sizes. Soil Sci. Soc. Am. J. 52: 1616–1621.

Sharpe, R., Schomberg, R. H. H., Harper, L. A., Endale, D. M., Jenkins, M. B., and Franzluebbers, A. J. (2004). Ammonia volatilization from surface-applied poultry litter under conservation tillage management practices. Environ. Qual. J. 33: 183–1188.

Sheehy, J., Regina, K., Alakukku, L., and Six J. (2015). Impact of no-till and reduced tillage on aggregation and aggregate-associated carbon in Northern European agroecosystems. Soil & Tillage Research 150: 107–113

Silva-Olaya, A. M., Cerri, C. E. P., La Scala Jr, N., Dias, C. T. S., and Cerri, C. C. (2013). Carbon dioxide emissions under different soil tillage systems in mechanically harvested sugarcane. Environmental Research Letters, 8(1), 015014.

Simunek, J., and Suarez, D. L. (1993). Modelling of carbon dioxide transport and production in soil 1. model development.

Six, J., and Paustian, K., (2014). Aggregate-associated soil organic matter as an ecosystem property and a measurement tool. Soil Biol. Biochem. 68, A4–A9.

Six, J., Conant, R. T., Paul, E. A., and Paustian, K. (2002). Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. Plant and soil, 241(2), 155-176.

Six, J., Elliott, E. T., and Paustian, K. (1999). Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Sci. Soc. Am. J. 63: 1350–1358.

Six, J., Elliott, E. T., Paustian, K., and Doran, J. W. (1998). Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Sci. Soc. Am. J. 62: 1367–1377.

Six, J., Elliott, E.T. and Paustian, K. (1999a). Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Science Society of America Journal, 63: 1350-1358.

Six, J., Paustian, K., Elliott, E. T., and Combrink, C. (2000). Soil structure and organic matter: I. Distribution of aggregate size classes and aggregate-associated carbon. Soil Sci. Soc. Am. J. 64: 681–689.

Six, J., Schultz, P.A., Jastrow, J.D. and Merckx, R. (1999b). Recycling of sodium polytungstate used in soil organic matter studies. Soil Biology and Biochemistry, 31: 1193-1196.

Skidmore, E. L., Layton, J. B., Armbrust, D. V., and Hooker, M. L. (1986). Soil physical properties as influenced by cropping and residue management. Soil Sci. Soc. Am. J. 50: 415–419.

Skjemstad, J. O., Le Feuvre, R. D., and Prebble, R. E. (1990). Turnover of soil organic matter under pasture as determined by 13C natural abundance. Aust. J. Soil Res. **28**: 267–276.

Smith, D. R., and Owens, P. R. (2010). Impact of time to first rainfall event on greenhouse gas emissions following manure applications. Communications in Soil Science and Plant Analysis. 41: 1604–1614.

Smith, K., Ball, T., Conen, F., Dobbie, K., Massheder, J., and Rey, A. (2003). Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes Eur. J. Soil Sci. 54: 79–91

Sommer, S., G., and Hutchings, N. J. (2001). Ammonia emissions from field applied manure and its reduction. European Journal of Agronomy. 15: 1–15.

Staben, M. L., Bezdicek, D. F., Fauci, M. F., and Smith, J. L. (1997). Assessment of soil quality in conservation reserve program and wheat-fallow soils. Soil Science Society of America Journal, 61 (1), 124-130.

Stemmer, M., Von Lützow, M., Kandeler, E., Pichlmayer, F., and Gerzabek, M. H. (1999). The effect of maize straw placement on mineralization of C and N in soil particle size fractions. European Journal of Soil Science, 50(1), 73-85.

Su, Y. Z., Wang, F., Suo, D. R., Zhang, Z. H., and Du, M. W. (2006). Long-term effect of fertilizer and manure application on soil-carbon sequestration and soil fertility under wheat-wheat-maize cropping system in northwest China. Nut. Cyc. Agroecosys. 75: 1-3.

Subhadip, G., Brian, W., Subrata, K. G., Nimai, S., and Biswapati, M. (2010). Management of soil quality and carbon sequestration with long-term application of organic amendments. 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1 – 6 August 2010, Brisbane, Australia.

Sundermeier, A., R. Reeder, and R. Lal. 2005. Soil carbon sequestration fundamentals. Rep. No. OSU Factsheet AEX-510–05. OSUE, Columbus, OH. Available online at http://ohioline.osu.edu/aex-fact/0510.html (verified 4 Mar. 2013).

Taylor, T. S., Titshall, L. W., Hughes, J. C., & Thibaud, G. R. (2012). Effect of tillage systems and nitrogen application rates on selected physical and biological properties of a clay loam soil in KwaZulu-Natal, South Africa. South African Journal of Plant and Soil, 29(1), 47-52.

Thierfelder, C., Matemba-Mutasa, R., and Rusinamhodzi, L. (2015). Yield response of maize (Zea mays L.) to conservation agriculture cropping system in Southern Africa. Soil and Tillage Research, 146, 230-242.

Tisdall, J. M. (1996). Formation of soil aggregates and accumulation of soil organic matter. **In**: Structure and Organic Matter Storage in Agricultural Soils. pp. 57–96, Carter, M. R. and Stewart B. A., Eds., CRC Press, Boca Raton, FL.

Tisdall, J. M., and Oades, J. M. (1982). Organic matter and water stable aggregates in soils. J. Soil Sci. 33: 141–163.

USDA Natural Resources Conservation Services. Fact sheet on Soil Quality Indicators, (June, 2008).

Ussiri, D. A., and Lal, R. (2009). Long-term tillage effects on soil carbon storage and carbon dioxide emissions in continuous corn cropping system from an alfisol in Ohio. Soil and Tillage Research, 104(1), 39-47.

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

VandenBygaart, A. J., Gregorich, E. G., and Angers, D. A. (2003). Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. Can. J. Soil Sci. 83: 363–380.

Walkley, A., and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil science, 37(1), 29-38.

Wan, Y., and El-Swaify, S. A. (1996). Sediment enrichment mechanisms of organic carbon and phosphorus in a well-aggregated Oxisol. J. Environ. Qual. 27: 132–138.

Wang, H. B., McConkey, D., Curtin, and H. Cutforth. (2010). Estimation of daily soil CO2 flux using a single-time-point measurement. Canadian Journal of Soil Science 90: 517–522.

Watts, C. W., Whalley, W. R., Longstaff, D., White, R. P., Brooke, P. C., and Whitmore, A. P. (2001). Aggregation of a soil with different cropping histories following the addition of organic materials. Soil Use Manage. 17: 263–268.

Whalen, J. K., and Chang, C. (2002). Macroaggregate characteristics in cultivated soils after 25 annual manure applications. Soil Sci. Soc. Am. J. 50: 1637–1647.

Wild, A. (1988). Russell’s soil conditions and plant growth. 11th ed., John Wiley & Sons, Inc. New York.

WRB, 2006. World reference base for soil resources 2006. World Soil Resources Reports No. 103. FAO, Rome.

Xu, M., and Y. Qi. (2001). Soil surface CO2 efflux and temporal variations in a young Ponderosa Pine plantation in northern California. Global Change Biology 7: 667–677.

Yang, X. M., Craig, F. D., and Wander, M. M. (2013) A wide view of no-tillage practices and soil organic carbon sequestration, Acta Agriculturae Scandinavica, Section B- Soil & Plant Science, 63:6, 523-530

Yang, X.M., and Wander, M. M. (1999). Tillage effects on soil organic carbon distribution and storage in a silt loam soil in Illinois. Soil Till Res. 52:1-9.

Yang, Z., Singh, B. R., and Sitaula, B. K. 2004. Fractions of organic carbon in soils under different crop rotations, cover crops and fertilization practices. Nut. Cyc. Agroecosys. 70: 161–166.

Yu, H., Ding, W., Luo, J., Geng, R., Ghani, A., and Cai, Z. (2012). Effects of long-term compost and fertilizer application on stability of aggregate-associated organic carbon in an intensively cultivated sandy loam soil. Biology and Fertility of Soils, 48(3), 325-336.

Zak, D. R., Tilman, D., Parmenter, R. R., Rice, C. W., Fisher, F. M., Vose, J., Milchunas, D., and Martin, C.W. (1994). Plant production and soil microorganisms in late-seccessional ecosystems: a continental-schale study. Ecology, 75 (8) 2333-2347.

Zhang, L., Wei, X., Hao, M., and Zhang, M. (2015). Changes in aggregate-associated organic carbon and nitrogen after 27 years of fertilization in a dryland alfalfa grassland on the Loess Plateau of China. Journal of Arid Land, 7(4), 429-437.

Zheng, H., Ouyang, Z., Xu, W., Wang, X., Miao, H., Li, X., and Tian, Y. (2008). Variation of carbon storage by different reforestation types in the hilly red soil region of southern China. Forest Ecol Manag 255: 1113-1121.

APPENDICE

Appendix 1: Monthly rainfall data at Anwomaso during the study period

Month	Total monthly rainfall (mm)
March	99
April	89.5
May	75
June	164
July	52
August	34
September	84.9
October	143
November	39
December	20

Source: KNUST weather station

Appendix 2. Poultry manure characterization

Manure analysis	**Oc**	**CN ratio**	**N (%)**	**P (mg/kg)**	**K (cmol/kg)**
	30.66	10.8	2.84	1.74	3.04

PM = poultry manure; HR = half rates of PM and NPK; NA = no amendment; N/S = no significance.

Appendix 3: Soil chemical parameters and their ratings

Soil Parameter	**Rating**
Soil organic carbon (% of soil by weight)	
< 2	Very low
2-4	Low
4-10	Medium
10-20	High
> 20	Very high

Source: Landon (1996)

Soil Parameter	Rating
Soil pH	
< 5.0	Very acidic
5.0-5.5	Acidic
5.6-6.0	Moderately acidic
6.1-6.5	Slightly acidic
6.6-7.0	Neutral
7.1-7.5	Slightly alkaline
7.6-8.5	Alkaline
>8.5	Very alkaline
Nitrogen (%)	
< 0.1	Low
0.1-0.2	Moderate
> 0.2	High
Calcium ($cmol_{(c)}Kg^{-1}$) (Mg = 0.25)	
< 5	Low
5-10	Moderate
> 10	High
Exc. Potassium ($cmol_{(c)}Kg^{-1}$)	
< 0.2	Low
0.2-0.4	Moderate
> 0.4	High
ECEC ($cmol_{(c)}Kg^{-1}$)	
< 10	Low
10-20	Moderate
> 20	High

Source: Soil Research Institute of Ghana (CSIR)