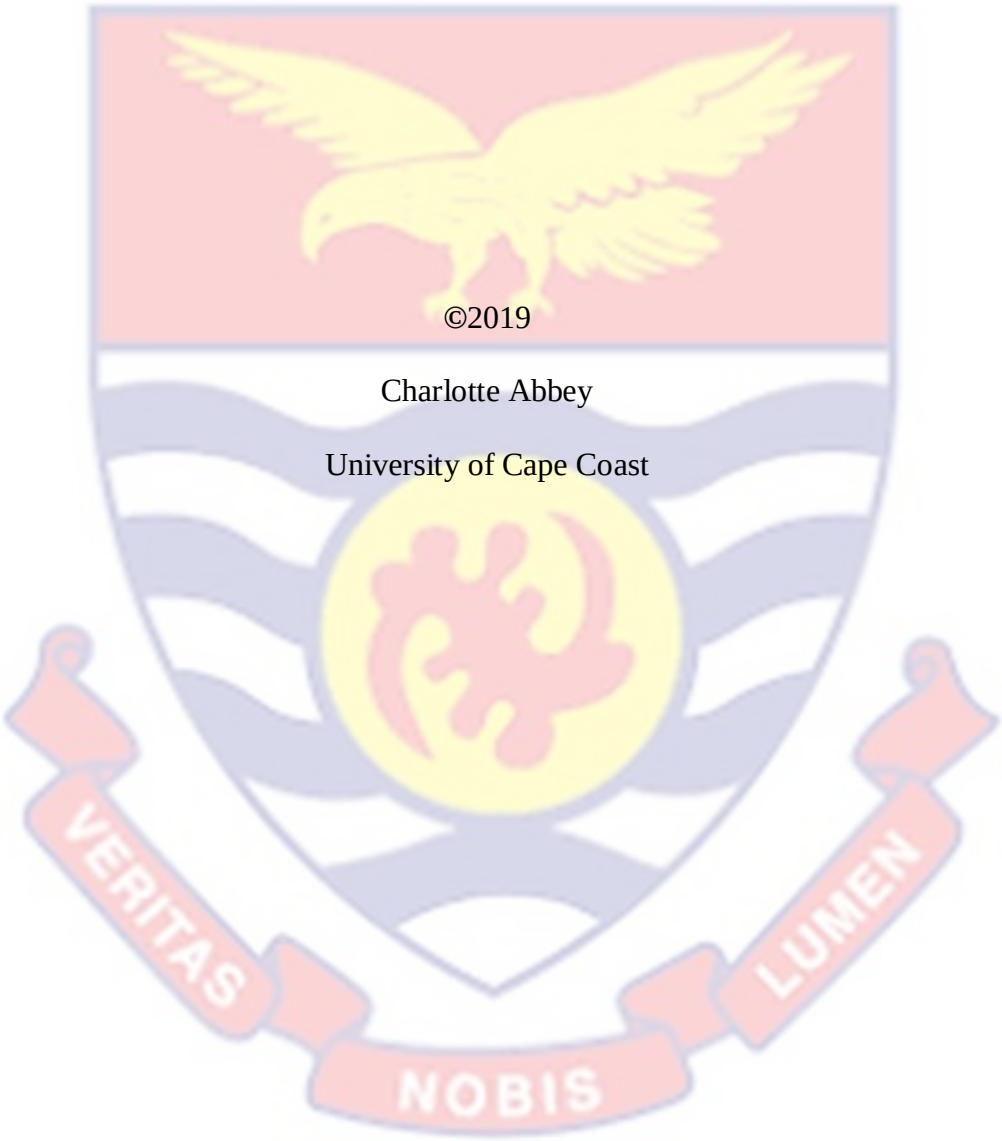
UNIVERSITY OF CAPE COAST

EFFECT OF COMPOST AND BIOCHAR ON SOIL FERTILITY AND CABBAGE YIELD

CHARLOTTE ABBEY

2019



Charlotte Abbey

University of Cape Coast

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EFFECT OF COMPOST AND BIOCHAR ON SOIL FERTILITY AND CABBAGE YIELD.

BY

CHARLOTTE ABBEY

Thesis submitted to the Department of Soil Science of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Land Use and Environmental Science

APRIL, 2019

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:..... Date:.....

Name: Charlotte Abbey

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:..... Date:.....

Name: Prof. Kwame Agyei Frimpong

Co-Supervisor's Signature: ..... Date:.....

Name: Dr. Edward Akwasi Ampofo

ABSTRACT

Soil fertility decline remains the major biophysical constraint to low crop productivity on farmlands. Even though inorganic fertilizers play significant role in increasing crop production, they are not a sustainable solution in maintaining high crop yields as it gradually deteriorates soil physico-chemical properties which subsequently reduce crop yield. Both pot and field experiments were conducted to determine the effect of combined application of compost and biochar on soil pH, total nitrogen, available phosphorus, nutrient use and efficiency, total organic carbon, bulk density, field capacity, hydraulic conductivity as well as the yield of cabbage (test crop). A completely randomised design and randomised complete block design were used for pot and field experiments respectively with 3 cabbage varieties for the pot and 2 cabbage varieties for the field. Total microbial count in log/cfu was determined using the total plate count. Five treatments were evaluated, sole biochar (B), sole compost (C), compost + biochar (CB), NPK fertilizer (NPK) and control (no application). There was no significant difference among the treatments in all the soil parameters measured for pot experiment except the pH for NPK which was lower (5.83) compared to B (6.58), C (6.47) and CB (6.51). In the field experiment, B and CB increased total organic carbon (1.21% and 1.54% respectively). The C and CB increased the crop yield, soil total N and soil available P concentrations. Application B also increased soil microbial population. A combination of compost and biochar can therefore be used as a soil amendment to increase yield and improve soil physico-chemical properties under field conditions.

ACKNOWLEDGMENTS

I am grateful to Prof. Kwame Agyei Frimpong, my principal supervisor, for the opportunity given me and his guidance throughout my study. I am also grateful to Dr. Edward Akwasi Ampofo, my Co-supervisor, for his advice towards my work. I also appreciate the efforts of Dr. Grace Van der Puije, Dr. Josiah Tachie Menson, Mr. Mawuli Agbale and lecturers in my Department; Prof. Daniel Theophilus Okae Anti, Prof. B. A. Osei, and Dr Christian Phares and Dr Kofi Atiah. I also thank Messrs Osei Agyeman and Stephen Adu of Soil Science and Animal Science Laboratories respectively of the University of Cape Coast. I am also grateful to Dr. Francis Addy for his support and review. Mr. Paul Acquah, the laboratory assistant is also well appreciated. I am also grateful to my father, Mr. William Abbey, my deceased mother, Mrs Mary Abbey (Maafio Obinim) and my siblings Florence, Rita, Lydia, Eunice and Godson for their enormous prayer support. To my lovely nieces and nephews Erica, Johanna, Abeiku, Kofi Claude and Kwabena Nyamekye. and my friends Sis Naanyo, Naa Yemorkor, Boatemaa, Ocran, Efo Sammy, Sir Law, I say God richly bless you.

Finally, I am most grateful to both the Central assembly and the Latter house assembly of the Church of Pentecost (Russia Worship Centre) for praying with me throughout the studies, I say God richly bless you.

DEDICATION

Dedicated to my deceased mother, Mrs Mary Deidei Abbey (Maafio Obinim).

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CSIR	Council for Scientific and Industrial Research
FAO	Food and Agriculture Organisation
PSD	Particle Size Distribution
SED	Standard Error of Difference
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
TOC	Total Organic Carbon
SSSA	Soil Science Society of America
USDA	United States Department of Agriculture
UV	Ultra-Violent
WHC	Water Holding Capacity

CHAPTER ONE

INTRODUCTION

Background to the study

Increasing population leads to over-exploitation of soil resources including nutrients and water for agriculture, leading to soil fertility decline and low crop yields (Boserup, 2017). Soil fertility decline remains a major biophysical constraint to crop productivity on farmlands (Partey, Saito, Preziosi, & Robson 2016). Excessive plants uptake of soil nutrients for growth causes soil nutrient depletion (Tan, Lal & Wiebe, 2005). Inorganic fertilizers have played a significant role in increasing crop production, (Qin, Liu, Shi, Tao & Yan, 2013) however, they are not a sustainable solution for maintenance of crop yields (Vanlauwe et al., 2010).

Soil is considered the main source of essential nutrients to plants, water reserves and a medium through which plants grow (Ghaemi, Astaraei, Emami, Nassiri, & Sanaeinejad, 2014). It is therefore very vital to maintain or improve soil quality for agricultural productivity and environmental safety to satisfy the food demand of the present and future generations (Reeves 1997).

Inorganic fertilizers are easy to use and can rapidly provide nutrients to soil as they are often soluble, however, their continuous use of in high rates for several years, leads to unsustainable crop production and also pose a threat to the environment as 10 to 20% of urea applied to soil is lost to the atmosphere as ammonia (NH_3) (Harrison & Webb, 2001).

Compost is formed from organic materials that have been decomposed and recycled to be used as fertilizers or soil amendment (Adamtey, Cofie , Ofosu-Budu, Danso & Forster 2009). A study conducted by Cogger, Hummel,

Hart & Bary, (2008) indicates that incorporating compost into the top few centimetres of the soil are easily broken down by soil microbes and impacts positively on soil carbon, nitrogen and bulk density.

Biochar is rich in carbon and offers agronomic benefits through soil quality improvement (Lehmann et al., 2011) and carbon sequestration in soils to offset anthropogenic greenhouse gas emissions (Sohi, Krull, Lopez-Capel, & Bol, 2010). Sustainable use of biochar can reduce to 12% the global net emissions of greenhouse gases caused by anthropogenic carbon emissions (Woolf, Amonette, Street-Perrott, Lehmann & Joseph, 2010).

Biochar addition may increase specific soil surface area; improves aggregate stability, nutrient and water retention (Atkinson, Fitzgerald & Hipps, 2010); increases enzyme activity (Bailey, Fansler, Smith & Bolton, 2011); enhances nitrogen and phosphorus cycling (Van Zwieten et al., 2010), decrease soil acidity (Oguntunde, Fosu Ajayi, & Van De Giesen, 2004) It also increases water and air availability to crops and stimulates microbial activity (Durenkamp, Luo & Brooks 2010).

Cabbage is cultivated for its densely leaved heads, produced during the first year of its biennial cycle. Cabbage plants perform better in well-drained soil at sites with complete sunlight. Different varieties prefer different soil types, ranging from lighter sand to heavier clay, but all prefer fertile ground with a pH between 6.0 and 6.8 (Bradley, Ellis & Martin, 2010).

Problem statement

Inorganic fertilizer use by farmers is constrained by high cost and unreliable supply (Sanginga et al., 2003). Long-term overuse of inorganic fertilizers may accelerate soil acidification, affecting both the soil biota and biogeochemical processes, thus posing an environmental risk and decreasing crop production due to mineralization of organic matter (Palm, Gachengo, Delve, Cadisch, & Giller, 2001).

Although compost application improves soil physicochemical properties, it loses its potential under high temperature and moisture conditions resulting rapid mineralization and loss of nutrients due to leaching and gaseous emissions (Bernal, Sanchez-Monedero, Paredes, & Roig, 1998). Biochar on the other hand mineralizes in a biphasic pattern as the labile compounds mineralises rapidly after which the recalcitrant carbon degrades slowly (Cross & Sohi, 2011).

Justification

Compost application offers the potential to improve soil fertility as it provides micro and macro nutrients to the soil. Compost mineralizes rapidly in high temperature and moisture conditions leading to rapid nutrient loss. Biochar applied together with compost can adsorb nutrients and release them slowly for judicious use by the plants. Thus, addition of biochar to compost will minimize pollution of ground water from leached nutrients. Furthermore, combined biochar and compost application can minimize greenhouse gas emissions because the recalcitrant biochar carbon can lower N mineralization from compost, thereby reducing the available N and labile carbon substrates that drive CO_2, CH_4 and N_2O production in soil.

Application of biochar and compost, both of which can be produced locally from crop residues and/or animal manure, will minimize production cost whiles increasing yield and ensuring sustainable agricultural intensification of the scarce land resources. The use of biochar and compost by smallholder farmers will improve the quality of the soil, crop yield and enhance their livelihoods

Hypothesis

The hypotheses underlying the research are as follows:

1. Combined application of compost and biochar improves soil quality indices such as soil field capacity, hydraulic conductivity, cation exchange capacity, pH, and organic matter content as well as soil microbial activity better than sole application of biochar or compost.
2. Adding biochar to compost results in an effective synchrony between N and P release from compost mineralization and crop uptake through temporarily N or P fixation on biochar surfaces leading to higher N and P availability for crop uptake compared to sole application of compost or biochar.
3. Combined application of compost and biochar provides greater liming effects and hence higher P availability for uptake and improved cabbage yield compared to sole application of biochar or compost.

Main Objective

The main objective of the study was to improve cabbage growth and yield through biochar and compost applications.

Specific Objectives

The specific objectives are to:

1. Assess the effect of compost and biochar applied solely or in combination on selected soil quality indices (Total Nitrogen, Available Phosphorus, Organic carbon, Soil pH, Hydraulic Conductivity, Bulk Density and Moisture Content).
2. Examine N and P use efficiency by cabbage in soil amended with biochar and/or compost.
3. Examine the effect of biochar and/or compost on the growth and yield of cabbage.

CHAPTER TWO

LITERATURE REVIEW

This chapter elaborates on previous studies related to the research topic. The review covered soil fertility and its decline, the effect of inorganic fertilizer on soil, importance of soil microorganisms on soil physiochemical properties, the importance of biochar to soil quality and the environment and the use of biochar and compost as soil amendment interventions in improving soil microbial population and physiochemical properties.

Soil fertility and its decline

Soil fertility is the ability of a soil to supply essential nutrients in adequate amounts for plant growth. It is one of the key determinants of crop yield in agriculture (Stockdale, Shepherd, Fortune, & Cuttle, S. P. 2002). Fertility of a soil is a limiting factor in agriculture especially under intensified production systems. Intensification of agriculture often increases soil erosion and nutrient loss and reduces biodiversity (Matson, Parton, Power & Swift, 1997).

In eastern Africa, various indicators are used to evaluate fertility status of soils such as crop growth vigour, yield, soil colour, weed type and degree of infestation on farmlands, appearance of rocky outcrops and crop wilting to evaluate soil fertility (Corbeels, Shiferaw, & Haile, 2000; Odendo, Obare & Salasya 2010).

In Ghana, farmer's knowledge and perceptions of soil fertility is rather based on observable plant and soil related characteristics including soil colour, crop yield, soil water holding/retention capacity, stoniness, difficulty to work soil, type and abundance of indicator weeds, colour of leaves and observable

deficiency symptoms on crops, crop growth rate and presence and abundance of soil macro-fauna (Dawoe, Quashie-Sam, Isaac, & Oppong, 2012). Indicators such as symptoms of gullies, soil productivity, soil depth, water holding capacity and crop yield performance are used to evaluate soil fertility change (Getahun, 2006).

Soil fertility is a constraint to crop production worldwide and has been a major challenge to food security and agro-ecosystem sustainability in sub-Saharan Africa (Sanchez, 2000). Soil nutrient studied two decades ago indicated that 200 million ha of arable land in Africa lost about 132 million tons of nitrogen (N), 15 million tons of phosphorus (P), and 90 million tons of potassium (K) over a 30-year period (Sanchez et al., 1997). Stoorvogel and Smaling (1990) estimated the per-hectare annual soil nutrient loss to exceed 10 kg N, 4 kg P, and 10 kg K in about 38 sub-Sahara African countries with highest depletion rates in East Africa (exceeding 40 kg N, 15 kg P, and 40 kg K). Drechsel and Gyiele (1999) had valued the monetary worth of such losses to about US$ 4 billion per year. Although soil nutrient deficiency can be effectively addressed with inorganic fertilizers, economic and policy constraints limit their use especially in resource poor regions. In Africa, the cost of nitrogen fertilizer at the farm gate could be about two to six times higher than in Europe or North America (Mwangi, 1996). This high cost of inorganic fertilizer further complicates production challenges for the smallholder farmer. For instance, the removal of subsidies on mineral fertilizers in Ghana in the mid-1990s led to a decline in utilization by 60 % (Drechsel and Gyiele, 1999) and consequently a decline in production. Without subsidy, inorganic fertilizer in sufficient quantities is often beyond the financial reach of smallholder farmers.

Organic fertilizer is usually proposed as economically beneficial and environmentally sustainable substitute to mineral fertilizer but the former is not without constraints. The use of organic fertilizer alone is not able to meet crop nutrient requirements and its use as a supplement to inorganic fertilizers has been recommended under various production systems. The combination of organic and inorganic fertilizers has been shown to improve soil fertility, crop yield and maintain soil organic matter (Vanlauwe et al., 2001). Nevertheless, success of this combined nutrient management is dependent on the availability and affordability of inorganic fertilizers, type and quantity of organic materials available and the proportions at which the two nutrient sources are applied.

Effect of inorganic fertilizer on soil physico-chemical properties

Globally, the continuous use of inorganic fertilizers is known to lead to reduction in soil organic matter (SOM) content of cultivated lands (Sleutel, De Neve, Prat Roibas, & Hofman, 2005). This is as a result of hastened decomposition of SOM by nutrients from inorganic fertilizers and consequently leading to degradation of soil structure. Long term application of mineral fertilizer therefore deteriorates agricultural soils quality. Soil organic matter has multiple beneficial effects on soil structure such as improvement of water holding capacity, aeration and permeability, and it improves soil fertility, crop yield and ensures soil sustainability (Madrid, Lopez, & Cabrera, 2007; Freixo, de A Machado, dos Santos, Silva & de S Fadigas, 2002; Weil & Magdoff, 2004; Von Lützow, Leifeld, Kainz, Kögel-Knabner, & Munch, 2002). These benefits of SOM notwithstanding, excessive application may have negative effects on the environment such as pollution of water resources by leached nutrients.

Soil Quality

Soil quality is defined as 'the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation' (Karlen et al., 1997). Soil quality is a primary indicator of how sustainable a land is being used or managed (Gong, Ran, He, & Tiyip, 2015). The Soil Science Society of America (SSSA) defines sustainability as "managing soil and crop cultural practices so as not to degrade or impair environmental quality on or off site, and without eventually reducing yield potential as a result of the chosen practice through exhaustion or either on-site resources or non-renewable inputs" (SSSA, 1997).

Soil Quality Indicators

Soil quality indicators are measurable soil attributes that reveals soil productivity response or soil environment functionality, and are used to determine soil quality improvement rate (Ghaemi, Astaraei Emami, Nassiri, & Sanaeinejad, 2014). A range of parameters of soil physical, chemical and biological properties defines soil quality (Adeyolanu, Are, Oluwatosin, Ayoola & Adelana, 2013; Giacometti et al., 2013; Winding *et al*. 2005; Schloter et al., 2003; Anderson. 2003; Arshad & Martin 2002; Reeves, 1997). These parameters include aggregate stability, bulk density, water holding capacity, soil strength, soil colour, cation exchange capacity (CEC), capacity to form ligands and complexes, interaction of soil organic matter (SOM) and soil biology, compaction characteristics, friability, and pH (Murphy, 2015).

Soil pH

Soil pH is a measure of acidity or alkalinity of a soil. It is considered a master variable in soils that affects many chemical processes such as plant nutrient availability. Soil pH between 6.5 (lightly acidic) to 7.5 (slightly alkaline) is considered ideal for agriculture production, outside this pH range, soils would be unsuitable for agricultural purpose, thus, limiting soil quality (Dadhawal, Mandal, & Shrimali, 2011). Natural soil pH depends on the mineral composition of the parent material of the soil, and the weathering reactions that led to formation of the soil. Soil pH is also affected by climatic conditions. In warm humid environments, soil acidification occurs over time as the products of weathering are leached by water moving laterally or downwards through the soil. On the other hand, soil pH in dry climates is often neutral or alkaline, due to the limited weathering and leaching (Odendo et al., 2010, Teklu, and Gezahegn, 2003).

Soil Nitrogen

There are no minerals containing nitrogen in soil, hence reserves of N depend on the soil organic matter (SOM) content. Nitrogen cycling in soil is therefore closely related to organic matter turnover. Micro-organisms are responsible for soil-N transformations, which play a key role in determining the availability of N for plant growth and crop production (Murphy, Stockdale, Brookes, & Goulding, 2007).

Nitrogen is a nutrient required by plants in relatively larger amounts than other soil borne elements; endogenic application to crops often results in yield improvement. In agricultural systems, nitrogen is obtained from the soil through mineralization of soil organic matter and from external sources, both organic

and inorganic. Apart from some leguminous plants, that can obtain N from the atmosphere, most species obtain it only from the soil. For an optimal yield, the N supply must be available according to the needs of the plant, matching its pattern and total amount (Evett, 2008).

The presence of N enhances proteins and chlorophyll synthesis in turn promotes assimilation and synthesis CO_2 and carbohydrates respectively (Kumari, Ranjan, Sharma, Agarwal, & Sinha, 2012), Nitrogen stimulates root growth, crop development, and nutrients uptake (de Melo, W. J., de Melo, G. M., de Melo, V. P., Donha, & Delarica, 2018). Compared to well-drained silt and clay, nitrogen leaches rapidly in sandy soils due to its poor water retention (Leary, Rehm, & Schmitt, 2014).

Soil phosphorus

Phosphorus is derived from the weathering of minerals in parent rock material and is a major element in soil organic matter, and in natural terrestrial ecosystems (Lajtha, Driscoll, Jarrell & Elliott, 1999). It is usually the second most limiting nutrient for terrestrial primary production (after nitrogen).

Phosphorus contained in organic amendments and matter within the soil system is dependent on microbes which facilitates its bioavailability.

The bioavailability processes are also dependent on the available decomposable organic carbon in the soil. This signifies the importance of maintaining organic matter concentrations within the soil to support large microbial populations and activities (Kemmitt et al., 2008).

Soil organic carbon

Soil organic carbon (SOC) refers only to the carbon component of organic compounds. Soil organic carbon is divided between living soil biota and dead biotic material derived from biomass. Together these comprise the soil food web, with the living component sustained by the biotic material component. Soil biota includes earthworms, nematodes, protozoa, fungi, bacteria and different arthropods. Soil organic carbon tends to be concentrated in the topsoil. Most upland soils contain 0.5-3% organic carbon. Soils in desert areas mostly contains less than 0.5% organic carbon. A soil is rated as organic when it contains 12-18% more organic carbon. High levels of organic carbon develop supporting wetland ecology, flood deposition, fire ecology and human activity. Fire derived forms of carbon are present in most soils as unweathered charcoal and weathered black carbon (Skjemstad, 2002). Soil organic carbon in char is typically 5 - 50% (Schmidt, 2001) with levels above 50% encountered in mollisol, chernozem and terra preta soils (Hayes, Mylotte, & Swift, 2017). Root exudates are another source of soil carbon (Mergel, Timchenko, & Kudeyarov, 1998). About 5 - 20% of the total plant carbon fixed during photosynthesis is supplied as root exudates in support of rhizospheric mutualistic biota (Hobbie, & Hobbie, 2006, Pearson & Jakobsen. 1993).

Bulk density

Bulk density is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and the volume of pores among soil particles. It reflects the soil's ability to function for structural support, water and solute movement, and soil aeration. It is typically expressed in g/cm^3 and also used to convert between

weight and volume of soil. It is used to express soil physical, chemical and biological measurements on a volumetric basis for soil quality assessment and comparisons between management systems. This increases the validity of comparisons by removing error associated with differences in soil density at time of sampling (Arshad, Lowery & Grossman 1996).

High bulk density is an indicator of low soil porosity and soil compaction. It may cause restrictions to root growth, and poor movement of air and water through the soil. Compaction can result in shallow plant rooting and poor plant growth, influencing crop yield and reducing vegetative cover available to protect soil from erosion. By reducing water infiltration into the soil, compaction can lead to increased runoff and erosion from sloping land or waterlogged soils in flatter areas. In general, some soil compaction to restrict water movement through the soil profile is beneficial under arid conditions, but under humid conditions compaction decreases yields (Carter, 1990).

Hydraulic conductivity

Hydraulic conductivity, *k*, of a soil is the capacity of the soil to allow water to pass through it. The value of hydraulic conductivity is often used to measure the resistance of a soil to water flow (Coduto, 1999). Hydraulic conductivity is influenced by the viscosity and unit weight of the fluid flowing through the soil. Hydraulic conductivity depends on the direction of flow, which means that the vertical hydraulic conductivity would not be the same as the horizontal hydraulic conductivity. This condition of the soil is said to be anisotropic. A study conducted by Chen (2000) indicates that the value of vertical hydraulic conductivity (K_v) of a soil is usually higher than the horizontal hydraulic conductivity (K_h) in one or two orders of magnitude. The main factor

that affects the value of hydraulic conductivity is the average size of the pores between particles in the soil, which in turn is related to the distribution of particle sizes, particle shape and roughness, pore continuity, and soil structure (Hillel, 2012). Generally; the bigger the average sizes of the pores, the higher the value of hydraulic conductivity (Tuli, Kosugi, Hopmans &2001). The value of hydraulic conductivity of a soil that has a presence of small percentages of fines is normally significantly lower than the same soil without fines. In the other hand, the presence of crevices in clay will result in a much higher value of hydraulic conductivity compared to that of unfissured clay (Hillel, 2012).

Field capacity

Field Capacity is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased (Cassel & Nielsen, 1986). This usually takes place 2–3 days after rain or irrigation in pervious soils of uniform structure and texture. Field capacity is the bulk water retained in soil at −33 J/kg (or −0.33 bar) of hydraulic head or suction pressure. It is expressed symbolically as θ_{fc} (Stephens. 2018). The limitation observed in this measurement is that, it is affected by so many factors that is not precisely a constant (for a particular soil), yet it does serve as a practical measure of soil water-holding capacity. Field capacity improves on the concept of moisture equivalent and this concept was as an attempt to improve water use efficiency for farmers **(**Hsiao, Steduto & Fereres, 2007).

Field capacity is characterized by measuring water content after wetting a soil profile, covering it (to prevent evaporation) and monitoring the change in soil moisture in the soil profile. Water content when the rate of change is

relatively small is indicative of when drainage ceases and is called Field Capacity, (Nachabe, 1998).

Soil microbial activity

Microorganisms in soil are important because they affect soil structure and fertility. Soil microorganisms can be classified as bacteria, actinomycetes, fungi, algae and protozoa. Each of these groups has characteristics that define them and their functions in soil (Walker et al., 1999). Up to 10 billion bacterial cells inhabit each gram of soil in and around plant roots, a region known as the rhizosphere. The composition of the rhizobiome can change rapidly in response to changes in the surrounding environment. Over 33,000 bacterial and archaeal species on sugar beet roots (de Vrieze, 2015)

Microbes can make nutrients and minerals in the soil available to plants, produce hormones that spur growth, stimulate the plant immune system and trigger or dampen stress responses. In general, a more diverse soil microbiome result in fewer plant diseases and higher yield. Farming can destroy soil's microbial ecosystem (rhiziobiome) by using soil amendments such as fertilizer and pesticide without compensating for their effects. Healthy soil can increase fertility in multiple ways, including supplying nutrients such as nitrogen and protecting against pests and disease, while reducing the need for water and other inputs (Altieri, 2002).

Soil amendment

A soil amendment is any material added to a soil to improve its physical properties, such as water retention, permeability, water infiltration, drainage, aeration and structure. The goal is to provide a better environment for roots (Davis & Whiting, 2000). Amendments can be categorized into two groups that

i.e. organic and inorganic. There are two broad categories of soil organic amendments come from something that was alive include sphagnum peat, wood chips, grass clippings, straw, compost, manure, biosolids, sawdust and wood ash., this include. Inorganic amendments, on the other hand, are either mined or man-made e.g. vermiculite, perlite, tire chunks, pea gravel and sand.

Compost

Composts are organic matter that have been decomposed and recycled as fertilizers and soil amendment (Adamtey et al., 2009). In sub-Saharan Africa, there are opportunities for compost processing as municipal solid wastes provide between 17 and 80% of organic matter (Sharholy Ahmad, Mahmood, & Trivedi, 2007; Troschinetz & Mihelcic, 2009, Adamtey et al., 2009) Organic matter aids soil fertility in several ways, and compost as an important source of organic matter has primary impacts on important soil properties. Several authors (Benedek, Elfoughi, Abdorhim, Bayoumi, & Füleky, 2012) describe the high-nutrient mineralization potential of compost. This is the reason, why compost application can also increase nutrient supply of soil besides the increase of organic matter content, based on a high humus formation capacity.

Preparation of compost

Composts are organic matter that have been decomposed and recycled as fertilizers and soil amendment (Adamtey *et al*., 2009). Farm compost is made of ingredients which are available on the farm like wood chips and bark, manure, slurry, straw, crop residues, a surplus of grass and soil (Leroy, 2008). A study conducted by (Cogger et al., 2008) indicates that incorporating compost into the top few centimetres of the soil increase accessibility for microbes and

also contact with plants hence has a greater effect on soil carbon, nitrogen and bulk density compared to mulching.

Effect of compost on soil physico-chemical properties

Compost application can contribute to agricultural sustainability as continuous and adequate use of compost with proper management has been shown to have many advantages, which include providing a whole array of nutrients to soils, increasing soil organic matter (SOM) content, improving water holding capacity and other physical properties of soil like bulk density, penetration resistance and soil aggregation (DeLuca & DeLuca, 1997). Compared to mineral fertilizers, compost amended soils have the ability to decrease bulk density, improve porosity, hydraulic conductivity and aggregate stability (Edmeades, 2003). The decrease in bulk density has been attributed to the mixing of soil with less dense organic material. Compost as a soil amendment is said to cause an increase of the pH and attribute to the high pH value of most organic materials used for compost (D'Hose, Cougnon, Vliegher, Bockstaele & Reheul, 2012).

Biochar

Biochar is a soil amendment and aids in carbon sequestration (Roberts, Gloy, Joseph, Scott, & Lehmann, 2009). It is a high-carbon, fine-grained residue produced through modern pyrolysis processes; it is the direct thermal decomposition of biomass with little or no oxygen (preventing combustion), which produces a mixture of solids (the biochar proper), liquid (bio-oil), and gas (syngas) products. The specific yield from the pyrolysis is dependent on process conditions such as temperature and can be optimized to produce either energy or biochar (Gaunt and Lehmann, 2008). Pyrolysis occurs more quickly

at the higher temperatures, typically requiring seconds instead of hours. Temperatures of 400–500 °C produce more char, while temperatures above 700 °C favour the yield of liquid and gas fuel components. High temperature pyrolysis is also known as gasification, and produces primarily syngas, which has been used as vehicle fuel in some times and places (Winsley, 2007). Typical yields are 60% bio-oil, 20% biochar, and 20% syngas. By comparison, slow pyrolysis can produce substantially more char (~50%); it is this which contributes to the observed soil fertility of terra preta. Once initialized, both processes produce net energy. For typical inputs, the energy required to run a "fast" pyrolizer is approximately 15% of the energy that it outputs (Laird, 2008). Modern pyrolysis plants can use the syngas created by the pyrolysis process and output 3–9 times the amount of energy required to run (Lehmann, 2007)

Effect of biochar on soil physico-chemical properties

Biochar application offers a number of benefits for soil health. Many of these benefits are related to the extremely porous nature of biochar. The porous nature of biochar is very effective at retaining both water and water-soluble nutrients. Biochar is hygroscopic thus, it is a desirable soil material in many locations due to its ability to attract and retain water (Jeffery et al., 2011; Sukartono et al, 2011, Sohi, Lopez-Capel, Krull, & Bol, 2009). This is possible because of its porous structure and high surface area. As a result, nutrients, phosphorus, and agrochemicals are retained for the plants use. Plants are therefore healthier, and less fertilizer leaches into surface or groundwater (Asai et al., 2009).

Effect of compost and or biochar on soil microbial properties

Application of soil amendments such as compost and biochar are known to improve soil microbial load resulting from organic matter decomposition as well as the physical properties such as aeration and water holding capacity (Dempster, Gleeson, Solaiman, Jones, & Murphy, 2012). Soil microbes are responsible for soil humus formation, recycling of nutrients and contribute to the microbial biomass. Compost increases beneficial soil organism population, reduces plant pathogen population and has a beneficial effect on the growth of a variety of plants (D'Hose et al., 2012). Compost and biochar have been reported to increase nitrogen mineralization and soil microbial biomass (Garcia-Gil, Plaza, Soler-Rovira, & Poloet, 2000; Bernal et al., 1998).

Biochar provides suitable environment for many beneficial soil microorganisms and when pre-charged with these organisms, biochar becomes an extremely effective soil amendment promoting good soil, and in turn plant health (Ameloot, Graber, Verheijen & De Neve, 2013). Biochar has also been shown to reduce leaching of E-coli through sandy soils depending on application rate, feedstock, pyrolysis temperature, soil moisture content, soil texture, and surface properties of the bacteria (Abit, Bolster, Cantrell, Flores, & Walker, 2014). For plants that require high potash and elevated pH, biochar can be used as a soil amendment to improve yield (Lehmann et al., 2003). Biochar can improve water quality, reduce soil emissions of greenhouse, reduce nutrient leaching, reduce soil acidity, and reduce irrigation and fertilizer requirements (Zheng, Wang, Deng, Herbert, & Xing, 2013). It was also found under certain circumstances to induce plant systemic responses to foliar fungal diseases and

to improve plant responses to diseases caused by soil borne pathogens (Jaiswal, Elad, Graber & Frenkel, 2014).

The various impacts of biochar can be dependent on the properties of the biochar, as well as the amount applied (Jaiswal et al., 2014). Modest additions of biochar to soil reduce nitrous oxide (N_2O) emissions by up to 80% and eliminate methane emissions, which are both more potent greenhouse gases than CO_2 (Lehmann, 2007). Studies have reported positive effects from biochar on crop production in degraded and nutrient–poor soils (Bolster & Abit, 2012). Biochar can be designed with specific qualities to target distinct properties of soils (Novak et al., 2009). In a Columbian savanna soil, biochar reduced leaching of critical nutrients, created a higher crop uptake of nutrients, and provided greater soil availability of nutrients (Major, Rondon, Molina, Riha, & Lehmann, 2010).

Biochar application and rate

In developing countries, constraints on agricultural biochar relate more to biomass availability and production time. An alternative is to use small amounts of biochar in lower cost biochar-fertilizer complexes (Ameloot et al., 2013). At 10% levels, biochar reduced contaminant levels in plants by up to 80%, while reducing total chlordane and DDX content in the plants by 68 and 79%, respectively (Servin et al., 2015). Application rates of 2.5–20 tonnes per hectare (1.0–8.1 t/acre) appear to be required to produce significant improvements in plant yields. Biochar costs in developed countries vary from $300–7000/tonne, generally too high for the farmer/horticulturalist and prohibitive for low-input field crops. On the other hand, because of its high adsorption capacity, biochar may reduce the efficacy of soil applied pesticides

that are needed for weed and pest control (Graber, Tsechansky, Gerstl & Lew, 2012; Graber, Tsechansky, Khanukov & Oka 2011).

The cabbage plant

Cabbage (*Brassica oleracea* or *B. oleracea* var. *capitata*, var. *tuba*, var. *sabauda*) (Delahaut and Newenhouse,1997) or var. *acephala* is a member of the genus *Brassica* and the mustard family, Brassicaceae. Several other cruciferous vegetables are considered cultivars of *B. oleracea*, including broccoli, collard greens, brussels sprouts, kohlrabi and sprouting broccoli. All of these developed from the wild cabbage *B. oleracea* var. *oleracea*, also called colewort or field cabbage. This original species evolved over thousands of years into those seen today, as selection resulted in cultivars having different characteristics, such as large heads for cabbage, large leaves for kale and thick stems with flower buds for broccoli (USDA, 2012).

Morphology of the cabbage plant

Cabbage seedlings have a thin taproot and cordate (heart-shaped) cotyledon. The first leaves produced are ovate (egg-shaped) with a lobed petiole. Plants are 40–60 cm tall in their first year at the mature vegetative stage, and 1.5–2.0 m tall when flowering in the second year (Dixon, 2007). Cabbage heads ranges between 0.5 and 4 kg, with fast-growing, earlier-maturing varieties producing smaller heads (Delahaut & Newhouse, 1997).

Most cabbages have thick, alternating leaves, with margins that range from wavy or lobed to highly dissected; some varieties have a waxy bloom on the leaves. The initial leaves form a rosette shape comprising 7 to 15 leaves, each measuring 25–35 cm (10–14 in) by 20–30 cm (8–12 in) (Russo, 2008) after this, leaves with shorter petioles develop and heads form through the leaves

cupping inward (Delahaut & Newenhouse, 1997). The root systems of the plants are fibrous and shallow (Portas, 1973). About 90 percent of the root mass is in the upper 20–30 cm of soil with some lateral roots penetrating up to 2 m deep.

The inflorescence is an unbranched and indeterminate terminal raceme measuring 50–100 cm (20–40 in) tall, with flowers that are yellow or white (Russo, 2008). Each flower has four petals set in a perpendicular pattern, as well as four sepals, six stamens, and a superior ovary that is two-celled and contains a single stigma and style. Two of the six stamens have shorter filaments. The fruit is a silique that opens at maturity through dehiscence to reveal brown or black seeds that are small and round in shape. Self-pollination is impossible, and plants are cross-pollinated by insects (Katz & Weaver 2003).

Cabbage production

Cabbage is a cool-season crop generally requiring 60 to 100 days from sowing to reach market maturity, depending on the variety (Kemble, & Simonne, 1997). Even though it can be planted at stake, most cabbage production relies on the use of transplants. The ideal monthly temperatures for optimal growth and development ranges from 15ºC to 18ºC. Cabbage is generally grown for its densely leaved heads, produced during the first year of its biennial cycle.

Plants perform best when grown in well-drained soil in a location that receives full sun. Different varieties prefer different soil types, ranging from lighter sand to heavier clay, but all prefer fertile ground with a pH between 6.0 and 6.8 (Bradley et al., 2010). For optimal growth, there must be adequate levels of nitrogen in the soil, especially during the early head formation stage, and sufficient phosphorus and potassium during the early stages of expansion of the

outer leaves (Wien & Wurr, 1997). Cabbage is a rich source of vitamin C and vitamin K, containing 44% and 72%, respectively, of the Daily Value (DV) per 100-gram amount (right table of USDA nutrient values). Cabbage is also a moderate source (10–19% DV) of vitamin B6 and folate, with no other nutrients having significant content per 100-gram serving (USDA, 2014).

Nutrient use efficiency

Nutrient use efficiency is essential to differentiate plant species, genotypes and cultivars for their ability to absorb and utilize nutrients for maximum yields. Nutrient use efficiency (NUE) is calculated based on the following factors:

(a) uptake efficiency, which reflects nutrient acquisition from soil, influx rate into roots, influx kinetics, radial transport in roots based on root parameters per weight or length. Nutrient uptake is related to the amounts of the particular nutrient applied or present in soil.

(b) utilization efficiency, which is dependent on nutrient remobilization.

CHAPTER THREE

RESEARCH METHODOLOGY

Both pot and field experiments were carried out for the study. This chapter describes the study area, the experimental design and the sampling techniques that were used in the study. It also provides the description of the various activities undertaken during experiments period, the type of data, how and when they were collected as well as the protocols used in laboratory analyses of samples. The chapter also highlights the statistical tool and package that were used in the processing and analyses of data.

Study area

The study was conducted at the A.G. Carson Technology Centre of the University of Cape Coast. The site lies in the coastal savannah agro-ecological zone of Ghana (5°07'N, 1°17'W). Maximum rainfall is 1400 mm and minimum of 800 mm per annum. The mean monthly temperatures of the area ranges from 24°C to 28°C, with March being the hottest month (maximum temperature of 31°C). The mean monthly relative humidity is generally high and varies within 85% to 99% due to the sea breeze (FAO, 2005).

Study design

The compost was prepared by the pit method (Misra, Roy & Hiraoka, 2003) using poultry manure, *leucaena leucocephala* leaves and maize stovers in a proportion of 50: 20:30 respectively. The corn-cob biochar (charred at a temperature of approximately 450^{O}C) was obtained from the Soil Research Institute of the Council for Scientific and Industrial Research (SRI-CSIR).

A completely randomized design (CRD) was used in the pot experiment and a randomized complete block design (RCBD) was used for the field experiment

with each treatment replicated 3 (three) times. There were 5 treatments involving sole compost and biochar, combined compost and biochar,inorganic fertilizer (NPK) and the control in both the pot and field experiments. The amendments and application rates are summarised in Table 1.

Table 1: Soil Amendments used in the study and their application rates

TREATMENT	Biochar (tons ha^{-1})	Compost (tons ha^{-1})	Inorganic fertilizer (NPK)
Biochar only (B)	10	0	0
Compost (C)	0	10	0
Compost+Biochar (CB)	10	10	0
Inorganic fertilizer (NPK)	0	0	90:60:60 ($N:P_2O_5:K_2O$)
Control	0	0	0

Pot Experiment

The pot experiment was established between 3rd August to 12th October, 2017 (a period of 10 weeks). Slope sided plastic pots with lower and upper diameter of 22.7cm and 29 cm, respectively, height of 24.5 cm and a total volume of 14000 cm^3 was used for the pot experiment. The base of each pot was perforated to allow for water drainage. Each pot was filled with 14.4 kg of fine earth fraction (< 2 mm) soil after mixing thoroughly with amendments indicated in Table 1. The soil samples were collected from 0- 20 cm depth from an arable land with a history of maize monocropping without any fertilizer or biochar applications. The amended soils in the pots were watered to moisture content of 50 % and incubated for 2 weeks by placing them in a dark room at a temperature of about 25°C. The water content of pots with plants was kept

constant by mass balance throughout the experiment to ensure sufficient water supply to the cabbage plant. The pots with their contents were then put under a canopy to prevent waterlogging from rainfall.

The test crop for the pot experiment involved 3 different cabbage varieties: Fortune F1, Minoteur F2 and T-Cross. Five cabbage seeds per pot were planted at stake and thinning was done two weeks after planting leaving a seedling in each pot. Weeds were periodically removed by hand picking to avoid competition with cabbage seedlings for nutrients and space.

Data collection

Data was collected on the pot experiment 4 weeks after planting the test crop at 1week interval for 4 consecutive weeks to determine the effect of the amendment(s) on the growth rate of the cabbage plant.

Growth and Yield Data

Growth parameters were measured during the study to determine the growth rate of the cabbage plant as influenced by the treatments. The parameters measured included plant height (cm), number of leaves per plant and chlorophyll content index. Plant heights were measured from the base of the plant to the tip of the leaf using a measuring rule. The chlorophyll content index of the plant was determined with the CCM-200 plus (apogee instrument). Yield data was collected 10 weeks after planting. The yield parameters measured were the fresh and dry weights of the aboveground biomass and the root biomass. The fresh weight of the samples was measured with the electronic balance (FX-3000 IWP, SHS, inside suyer hybrid sensor by AND company limited) and oven dried at a temperature of 60^{o}C for 72 hours to a constant weight. The dry aboveground and root biomass samples from each treatment were milled

separately and stored in labelled zip lock bags and kept in a dry cool place (at a room temperature of 25^{o}C) prior to laboratory analyses.

Field experiment

Nursing of seeds

Nursery beds were prepared separately for each cabbage variety. The seeds were drilled in rows on the bed and covered with palm fronds to minimize heat and to ensure that moisture was retained against evaporation for rapid seed germination. The beds were watered daily and the palm fronds were removed three days after germination to enable the seedlings have access to adequate sunlight. The percentage germination rates of the different cabbage seeds nursed are summarised in Table 2.

Table 2: Germination percentage (%) of seeds of the cabbage varieties used

Variety	Germination Percentage (%)
Fortune F1	80
T-Cross	82.8
Minotaur F2	85.93

Seedlings were pricked out onto extra beds after 5 days to allow for establish proper establishment. Weak seedlings were thinned out periodically. The seedlings were transplanted onto the field 5 weeks after emergence.

Land Preparation

A total land size of 250 m^2 was cleared and used for field experiment. The field was subdivided into 30 plots, with each measuring 3 m x 2.4 m. The 5 treatments applied in the pot experiment were repeated for the field but only

two of the three cabbage varieties (Minateur F2 and Fortune F1) were used as test crops. Each plot had a total number of 20 cabbage stands with spacing of 60 cm within and between rows.

Biochar and Compost Application and Rates

Treatments with only biochar or compost were mixed thoroughly with the soil to a depth of approximately 20 cm. Combined biochar and compost treatments were mixed thoroughly before being incorporated into the soil. The amendments were applied 2 weeks prior to transplanting to allow them to be well conditioned in the soil.

Inorganic Fertilizer Application

The recommended rate for cabbage in this trial was 90 kg N ha^{-1}, 60 kg P_2O5 ha^{-1} and 60 kg K_2O ha^{-1}. Inorganic NPK 15-15-15 fertilizer was applied 7 days after emergence to supply N: P_2O5: K_2O, respectively, at rate of 14.4 g per plant by band placement. Urea was used to provide the supplementary 30% Nitrogen (N) at a rate of 2.4 g urea per plant also by band placement.

Soil sampling

Soil samples were collected from the whole field at a depth of 0-20 cm from 10 different selected spots along in a Z pattern to form a composite sample and stored for laboratory analyses. This was done before planting (before treating with amendments) and after harvesting (both pot and field trial). The pre-plant soil sampling was done to determine the initial soil physiochemical properties and those collected at after were analysed to assess the soil physicochemical properties after adding compost and/or biochar to the soil at different rates.

Data collection

Yield data collection

Plants were harvested at physiological maturity 12 weeks after transplanting. Six plants within the beds excluding border plants were harvested during the data collection. Parameters measured included weight of above ground biomass (Shoot), weight and circumference of head and weight of roots. Fresh weights of the samples were measured using the electronic balance (FX-3000 IWP, SHS, inside suyer hybrid sensor by AND company limited) and oven dried at a temperature of 60^{o} C for 72 hours to a constant weight.

The oven dried samples from each treatment were milled separately and filled into labeled zip lock bags and kept in a dry cool place prior to laboratory analyses.

Laboratory Analyses

The pre-treatment soil, biochar, compost and the post-harvest soil samples were characterized using standard laboratory methodology (Rowell, 1994). Soil chemical properties assessed included: pH, Organic carbon, Total

nitrogen and available phosphorus. Soil physical properties examined included: bulk density, particle size distribution, field capacity and hydraulic conductivity.

Soil particle size distribution (PSD)

The PSD was determined by pipette method described by Rowel (1994). Briefly, organic matter was destroyed by hydrogen peroxide and the remaining mineral soil dispersed by shaking in the presence of sodium hexametaphosphate. The soil was analysed by sedimentation using a pipette sampling technique. Approximately, 10 g of air-dry soil was weighed into 500 ml beaker and 10 mL of H_2O_2 was added. The beaker was allowed to stand till frothing ceased and another 10 mL of H_2O_2 was added. The content was gently heated on Bunsen flame and stirred at the same time to break the froth. H_2O_2 was further added with gentle heating using 100 mL of peroxide solution. Finally, the temperature was raised to boiling to complete the destruction of the organic matter and the content was allowed to cool.

To disperse the soil, the peroxide- treated soil was transferred quantitatively to 500 mL bottle with a screw cap using distilled water. A10 mL of dispersing agent (prepared by adding 50 g of sodium hexametaphosphate, 7 g of anhydrous sodium carbonate in a litre of water) was added. The content was made up to 200 ml and then shaken overnight on a mechanical shaker. After dispersing the soil, the content of the bottle was transferred to a 500 ml measuring cylinder and made up to 500 ml with distilled water.

Sampling of silt and clay followed, by drawing 20 ml of suspension with a special pipette after thorough mixing with plunger and allowed to settle for 32 seconds. The sedimentation started again after stirring for 8 h and clay was

sampled at a depth of 10 cm. Each of the 20 ml of suspensions was transferred into labelled weighed beakers and dried at 105˚C. After drying, the beakers were cooled in a desiccator and reweighed. These gave the mass of silt + clay + a small residue of the dispersing agent and mass of clay + a small residue of the dispersing agent. After another 8h, the sand was sampled by pouring away most of the supernatant liquid and quantitatively transferring the sediment known to be sand in to a beaker. Stirring, settling and decanting was done repeatedly until the supernatant was clear. The sand was transferred in to a weighed beaker, dried at 105˚C, cooled in a desiccator and reweighed. The mass of oven-dry soil was also determined and used for the calculation. The textural class of the soil was determined using the textural triangle after calculating the percentage of each particle size in the samples.

Calculation

$$The\ total\ mass\ of\ silt\ in\ the\ soil\ sample = mass\ of\ silt\ in\ 20ml\ X\frac{500}{20}$$

$$\%\ Sand = MS\ X\frac{100}{MdS}$$

$$\%\ Silt = MSi\ X\frac{100}{MdS}$$

$$\%\ Clay = MC\ X\frac{100}{MdS}$$

$Where$

$MS = mass\ of\ sand$

$MdS = mass\ of\ oven\ dry\ soil$

$MSi = mass\ of\ silt\ in\ soil\ sample$

$MC = mass\ of\ clay\ in\ soil\ sample$

Bulk density determination

Bulk density is a measure of the weight of the soil per unit volume expressed in g cm^{-3} (usually given on an oven-dry (105 °C) basis). Core samplers were driven into the soils with the aid of a hammer. Soils at both ends of the core sampler were trimmed with a straight-edged knife. The core samplers with their contents were then dried in the oven at 105 ˚C to a constant weight. The volume of the core sampler was determined by measuring height and radius of the core sampler.

Calculation

$pb = (W2 - W1)/V$

$Where$

$Pb = Dry\ Bulk\ Density$

$W2 = Weight\ of\ core\ cylinder + oven - dried\ soil$

$W1 = Weight\ of\ empty\ core\ cylinder$

$V = Volume\ of\ core\ cylinder\ (\pi\ r2\ h), where:$

$\pi = 3.142$

$r = radius\ of\ the\ core\ cylinder$

$h = height\ of\ the\ core\ cylinder$

Field moisture capacity determination

Field capacity or the water holding capacity (WHC) is the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially ceased from saturated soil (Veihmeyer & Hendrickson 1931). The soil field capacity was measured using core soil samples, a piece of clean cloth and rubber bands. The core soil samples were oven dried at a temperature of 105^{o}C and the weights recorded. The dried samples were covered with a piece of cloth at one end and tightened with rubber bands to hold it in place. The samples were placed in a bucket and filled with water to a depth just below the top of the samples to wet the samples from the bottom of the cylinders. The experiment was left overnight for water to be soaked via capillarity. The samplers were taken from the water and placed on a rack for excess water to drain.

Calculation for % Moisture at field Capacity

$$\%\, Moisture = (MW - DW)\, X\, 100/DW$$

$Where$

$MW = weight\ of\ moist\ soil$

$DW = weight\ of\ dry\ soil$

Hydraulic conductivity determination

Hydraulic conductivity an indication of the drainability of saturated soils. The constant head method described by Bonsu and Laryea, 1989 was used to determine the hydraulic conductivity. Plastic cylinders covered with a piece of cloth with rubber bands to hold it in place and rubber tapes to make it air tight. The samples were filled with soil and the sides of the cylinders were gently tapped to effect uniform packing. The samples were placed in a bucket and filled

with water to a depth just below the top of the samples to wet the samples from the bottom of the cylinders by capillary action. The samples were left overnight (at least 18 hours). Water was slowly poured into the upper part of the cylinder to the brim. A funnel and a measuring cylinder were connected at the bottom of the plastic cylinder and water was allowed to infiltrate through the soil until a uniform low was attained. The water level at the top of the cylinder was maintained at a constant level. The water level on top of the sample was allowed to stabilize and the percolate was collected into the measuring cylinder always maintaining the constant water level. The volume of the water was collected and was recorded at time t (3minutes) and the hydraulic head was measured. The experiment was repeated 3 times and the average value recorded.

Calculation

$K = (V/AT)\,(L/H)$

$Where\ V = volume\ of\ water\ collected\ in\ 3mins$

$A = Cross\ sectional\ area\ of\ the\ sample$

$L = Length\ of\ the\ sample$

$H = Hydraulic\ head$

$T = Time$

pH

Soil pH was measured in a 1:2.5 soil: water ratio using a glass electrode pH meter (Rowel, 1994). Approximately 10 g of air-dried soil was weighed into a plastic bottle with a screw cap. A 25 mL distilled water was added from a measuring cylinder and shaken for 15 minutes on a mechanical shaker. After calibrating the pH meter with pH buffers of 4.0 and 7.00, the pH was measured by inserting the electrode into the top of the soil water suspension and readings

were recorded. Each soil treatment was replicated three times and the average pH for each sample was calculated.

Organic carbon content determination

The organic carbon content of the soil was determined using the Walkley - Black method (FAO, 2008; Rowell, 1994). This involves a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid. After the reaction, the excess dichromate was titrated against ferrous sulphate (FAO, 2008). Approximately 0.5 g of soil samples was weighed in duplicates and transferred in to 500 mL Erlenmeyer flask, a blank was also included and the weights were recorded. By means of pipette, 10 mL of 0.167 M potassium dichromate ($K_2Cr_2O7_2$) was added to the soil and was gently swirled. A 20 mL of concentrated H_2SO_4 was also added and the flask was allowed to stand for 30 minutes. After 30 minutes of standing, the content was diluted with 200 mL of distilled water, swirling was repeated to ensure thorough mixing. In order to complex Fe3+ which would otherwise interfere in the end point, 10 mL and 0.2 g of H_3PO_4, NaF respectively was added before the addition of diphenylamine green end point.

Calculation:

The organic carbon content of soil was calculated as:

$$\%\ Organic\ Carbon = \frac{(B - S)\ X\ Molarity\ of\ Fe^2 + \ X\ 0.003\ X\ 100\ \ X\ 100}{Weight\ of\ Soil\qquad\qquad 77}$$

Where

$B\ =\ Blank\ titre\ value$

$S\ =\ sample\ titre\ value$

$0.300 = 12/4000 = milliequivalent\ weight\ of\ carbon$

$\frac{100}{77} = the\ factor\ converting\ the\ carbon\ actually\ oxidized\ to\ total\ carbon$

$100 = the\ factor\ to\ change\ from\ decimal\ to\ percentage.$

Determination of total nitrogen

The total nitrogen in the soil samples were determined by the Micro-Kjeldahl method described by Rowel (1994) with a slight modification. Much of the nitrogen in soil exists in the form of protein in which N is present primarily as the amino acid group (-NH_2) attached to carbon (-C-NH_2). In the Kjeldahl procedure, this form of N is oxidized to $(NH_4)_2SO_4$ by concentrated H_2SO_4. 0.5 g of soil was weighed into a digestion flask and 0.2 g catalyst and 3ml of conc. H_2SO_4 were added, two blanks were included. The flask and its content heated gently and gradually increased the heat to 380˚C for 2 hours on a block digester. On completion of digestion, the flask was allowed to cool and the content was diluted with 50 mL distilled water.

The steam distillation apparatus was set up and steam was passed through it for 20 minutes. After flushing the apparatus, 100 mL conical flask containing 5 mL of boric acid indicator was placed under the condenser of the apparatus. Using pipette, 20 mL aliquot of the sample digest was transferred to the reaction chamber through the trap funnel and10 ml of alkali mixture was added commencing the distillation to collect 50 ml of the distillate. The distillate was then titrated against M/140 HCl from green to wine red.

Calculation:

$\%\ N = (S - B)\ X\ Solution\ volume$

$$100X\ Aliquot\ X\ sample\ weight$$

Where

$S = Sample\ titre\ value$

$B = Blank\ titre\ value$

Available phosphorus (P) determination

Phosphorus is classified as a major nutrient, meaning that it is frequently deficient for crop production and is required by crops in relatively large amounts. The total P concentration in agricultural crops generally varies from 0.1 to 0.5 percent.

The available phosphorus in the soil samples were determined using Spectrophotometric method in which phosphate and ammonium molybdate form complex which is reduced with ascorbic acid to produce a blue colour in solution. 1 g of soil sample was weighed into a 15 ml centrifuge tube and 10ml of extracting solution (15 ml of NH_4+ 25 ml of 0.5 M HCl in 460 ml distilled water) was added. The content was filtered after shaking for 5 minutes on a mechanical shaker. 2ml aliquot of the extract was pipetted into 25 ml volumetric flask. 100 ml of 5 µg P/ml was prepared from stock solution of P. From of 5 µg P/ml solution, a set of working standards of P containing 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 µg P/ml were prepared in 25 ml volumetric flask. Both blank and P standards contained the same volume of extracting solution as the soil samples. 10 ml of distilled water was added to each flask and 4 ml of reagent (12 g ammonium molybdate in 250 ml water + 0.2908 g of potassium antimony tartarate in 100 ml distilled water + 2.5 M H_2SO_4 1L distilled water and made up to 2 L, to every 200 ml of this solution 1.156 g of ascorbic acid was dissolved) also added before topping up to the volume with distilled water. The

colour was allowed to develop for 15 minutes before determining the absorbance on spectrophotometer at 882 nm. Excel was used to plot a calibration curve using the concentrations and absorbance of the standard solutions and from the curve the concentrations of the samples were extrapolated.

Calculation:

$$\mu g\ P/g\ soil\ =\ C\ \times\ Dilution\ factor$$

Where

C is the concentration obtained from the graph

Plant analyses

The cabbage plant was analysed at maturity for the determination of N and P content as influenced by the different treatments of biochar and/or compost and their application rates. The roots, the above ground biomass and the head of the cabbage plant were analysed separately on the field study. The roots and the above ground biomass were analysed for the pot experiment. Each plant sample was milled to a very fine powder and stored in transparent zip-lock bags for further analysis (Galicia, Nurit, Rasales & Palacios-Rojas, 2009). The samples were prepared into solution for the determination of nitrogen and phosphorus. The organic matter was destroyed through acid oxidation before a complete elemental analysis was carried out. The sample solutions were therefore prepared to necessitate the oxidation process.

Sulphuric Acid-Hydrogen peroxide digestion

The digestion mixture comprised 350 ml of hydrogen peroxide, 0.42 g of selenium powder, 14 g of lithium sulphate and 420 ml sulphuric acid. The digestion procedure as outlined by Stewarts et al. (1974) was followed. A 0.2 g

of the milled sample was weighed into a 100 ml Kjeldahl flask and 4.5 ml of the mixed digestion reagent was added to the samples and digested at 360 ˚C for two hours. Blank digestions (digestion of a mixture without sample) were carried out in the same way. After the digestion, the digests were transferred quantitatively into 100 ml volumetric flasks and made up to volume.

Determination of total nitrogen

A steam distillation apparatus was set up and steam was passed through it for 20 minutes. After flushing the apparatus, 100 ml conical flask containing 5 ml of boric acid indicator was placed under the condenser of the apparatus. Using pipette, 20 ml aliquot of the sample digest was transferred to the reaction chamber through the trap funnel and10 ml of alkali mixture was added commencing the distillation to collect 50 ml of the distillate. The distillate was then titrated against M/140 HCl from green to wine red.

Calculation:

$$\%N = (B - S)X\ Solution\ Volume/100\ X\ Aliqout\ X\ sample\ weight$$

Where

$S = Sample\ titre\ value$

$B = Blank\ titre\ value$

Determination of phosphorous

The available phosphorus in the plant samples were determined using Spectrophotometric method (Rowell, 1994). A millilitre aliquot of the sample digest was pipetted into 25 ml volumetric flask. About 100 ml of 5 µg P/ml was prepared from stock solution of P. From of 5 µg P/ml solution, a set of working standards of P containing 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 µg P/ml were prepared in 25 ml volumetric flask. Both blank and P standards contained the same

volume of extracting solution as the plant samples. A 10 ml of distilled water was added to each flask and 4 ml of reagent (12 g ammonium molybdate in 250 ml water + .2908 g of potassium antimony tartarate in 100 ml distilled water + 2.5 M H_2SO_4 1L distilled water and made up to 2 L, to every 200 ml of this solution 1.156 g of ascorbic acid was dissolved) also added before topping up to the volume with distilled water. The colour was allowed to develop for 15 minutes before determining the absorbance on spectrophotometer at 882 nm. Excel was used to plot a calibration curve using the concentrations and absorbance of the standard solutions; from the curve the concentrations of the samples were extrapolated.

Calculation:

$$\mu g\ P/g\ soil\ =\ C\ \times\ Dilution\ factor$$

C is the concentration obtained from the curve

Determination of Soil microbial counts

Total microbial count in the soil was determined on the control as well as the amended soils. This was carried out by the total plate count method as described by Chaudhry et al., (2012). Fresh soil samples were collected from the field very close (about 2cm) to the roots (rhizosphere) of the cabbage plant into zip lock bags in a cold chain for microbial analysis. Growth media was prepared by dissolving about 28 g of nutrient agar in 1000 ml of distilled water and autoclaved for an hour. All equipment and apparatuses for the experiment were autoclaved for at least an hour for sterilization. The experiment was conducted in a UV hood and all equipment and apparatuses used were kept in the hood to minimize contamination. Approximately 10 mL to 12 mL of the media was transferred into the petri dish, spread evenly and made to solidify.

Approximately, 0.01g of soil was transferred into eppendorf tubes and diluted with 1000 µl of peptone water. A 100µl of the diluent was picked from the dilution into a second tube containing 900 µl of the peptone water. The serial dilution was done till the sixth diluent. A 100 µl of the samples was then picked from the fifth and sixth diluent and inoculated onto separate petri dishes. A 100 µl of the first diluent was also inoculated. A glass spreader was used to spread the sample evenly on the petri dish. The samples were kept in an incubator at a temperature of 37° C for 24 hours. The growth on the plates were counted and recorded in log cfu.

Nutrient uptake and nutrient use efficiency

Nutrient uptake and Nutrient use efficiency were determined only for the field experiment.

Nutrient uptake was calculated to determine the amount of nutrient (N and P) utilized by the plant in kilogram per hectare.

Thus,

$$Nutrient\ uptake = Dry\ weight\ of\ plant\ x\ nutrient\ absorbed\ by\ plant/100$$

Nutrient efficiency ratio (NER) was proposed by Gabelman and Gerloff (1983) to differentiate genotypes into efficient and inefficient nutrient utilizers.

$$NER = Yields\ (kg)/Elements\ in\ tissue\ (kg)$$

$$Physiological\ efficiency\ (PE)\ is\ defined\ as$$

$$PE = \frac{Yield\ F\ (kg) - Yield\ C, (kg)}{Nutrient\ uptake\ F(kg)\ -\ Nutrient\ uptake\ C, (kg)}$$

$$Where:$$

F *is plants receiving fertilizer and* C *is plants without fertilizer.*

Agronomic efficiency (AE) *is expressed as the additional amount of economic yield per unit nutrient applied*:

$$AE = \frac{Yield\ F(kg) - Yield\ C\ (kg)}{Quantity\ of\ nutrient\ applied, kg}$$

$$Apparent\ physiological\ efficiency \quad (APE) = \frac{Yield\ F(kg) - Yield\ C(\ kg)}{Nutrient\ uptake\ F(kg) - Nutrient\ uptake\ C\ (kg)}$$

$$shoots + head \qquad shoots + head$$

Apparent nutrient recovery efficiency (ANR)*has been used to reflect plant ability to acquire applied nutient from soil*:

$$ANR = \frac{Nutrient\ uptake\ F,(kg) - Nutrient\ uptake\ C,(\ kg)x100}{(Quantity\ of\ nutrient\ applied,(\ kg))}$$

Nutrient use efficiency $(\boldsymbol{NUE})$

$$NUE = Uptake\ Efficiency\ X\ Utilization\ efficiency$$

$$Uptake\ efficiency = \frac{Total\ nutrient\ uptake\ kg\ ha^{-1}}{Amount\ of\ nutrient\ applied\ kg\ ha^{-1}}$$

$$Utilization\ efficiency = \frac{yield\ kg\ ha^{-1}}{Total\ nutrient\ uptake\ kg\ ha^{-1}}$$

Data analyses

The data was analysed using GenStat Edition 12 statistical software. Relationships between variables were established using correlations. Two-way

ANOVA in randomized blocks was used to determine the effect of treatments on soil physicochemical properties and cabbage growth and yield. Analysis of variance was performed to test the treatment effect for significance and means were separated using Fisher's Unprotected Lsd at 0.05 significance level.

CHAPTER FOUR

RESULTS

In both pot and field experiments, it was realised that the varieties did not differ significantly, hence yield on varieties were pooled together for the separate experiments. The mean physico-chemical properties of the soil, biochar and compost used for the experiments are summarised in Table 3.

Table 3: Physico-chemical properties of the soil, biochar and compost used in both the pot and the field study.

Parameter	Soil	Compost	Biochar
pH	6.3	8.4	8.3
Total nitrogen (%)	0.09	1.1	0.70
Available phosphorus (ug g^{-1})	6.3	93.35	31.5
Total organic carbon (%)	0.53	31.90	79.8
Bulk density (g cm^{-3})	1.56	NA	NA
Hydraulic conductivity (mm s^{-1})	22.47	NA	NA
Field capacity (%)	20.13	NA	NA
Particle size distribution	Sandy loam	NA	NA
Sand (%)	79.82	NA	NA
Clay (%)	8.04	NA	NA
Silt (%)	12.14	NA	NA

NA (not applicable)

The pH of the soil was slightly acidic and that of the compost and biochar were alkaline (Table 3). The total N concentrations in the soil, compost and biochar were 0.09, 1.1 and 0.70 %, respectively. The phosphorus concentration was 6.3, 93.35 and 31.5 (ug g^{-1}) and total organic carbon (TOC) were 0.53, 31.90 and 79.8 (%) for soil, compost and biochar respectively. Initial bulk density of 1.56 gcm^{-3}, hydraulic conductivity of 22.47mm s^{-1} and a field

capacity of 20.13% were also recorded. The textural class of the soil used for both pot and field experiments was sandy loam with particle size distribution of 79. 82% sand, 8.04% clay and 12.14% silt.

Effect of NPK, compost and/or biochar on soil physico-chemical properties of post-harvest soil.

The soil pH, organic carbon, total nitrogen and available phosphorus after the harvest are presented in Table 4 and 5 for pot and field study respectively.

Table 4: Chemical properties of post-harvest soil from the pot experiment.

Treatment	pH	O.C (%)	Tot. N (%)	Avai.P (ug g^{-1})
B (Biochar)	6.58a	0.81	0.08	61.05b
C (Compost)	6.47ab	0.91	0.07	62.76b
CB (Compost +Biochar)	6.51ab	0.61	0.08	68.11b
NPK	5.83c	1.28	0.09	83.27a
Control	6.29b	0.81	0.08	62.90b
P value	***	NS	NS	***

NS= not significant, *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P< 0.001. Means followed by the same letter in each column are not significantly different at P ≤ 0.0 5 using Fisher's unprotected LSD

O.C = organic carbon, Tot. N = total nitrogen, Avai. P= available P

Table 5: Physico-chemical properties of post-harvest soil from the field experiment.

Treatment	pH	O.C (%)	Tot. N (%)	Avai.P (ug g^{-1})	B.D (gcm^{-3})	M.C (%)	F.C (%)	H.C (mm s^{-1})
B (Biochar)	6.58	1.21	0.09	135.20	1.53	7.69	20.60	18.28
C (Compost)	6.482	0.83	0.07	101.30	1.49	7.46	20.89	24.03
CB (Compost +Biochar)	6.718	1.54	0.14	114.20	1.50	7.25	20.98	25.13
NPK	6.58	1.05	0.09	109.60	1.50	11.77	21.39	38.73
Control	6.24	0.63	0.06	69.0	1.52	7.18	20.46	25.90
P value	NS	***	*	NS	NS	NS	NS	***
S.E.D	0.19	0.13	0.02	28.47	0.06	2.48	1.91	3.51

NS= not significant, *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P< 0.001. Means followed by the same letter in each column are not significantly different at P ≤ 0.0 5 using Fisher's unprotected LSD.

O.C = organic carbon, Tot. N = total nitrogen, Avai. P= available P, B.D = bulk density, M.C =moisture content, F.C= field capacity, H.C = hydraulic conductivity

There was no data gathered on physical properties for the pot experiment hence results on physical properties was only for the field experiment.

The NPK treatment impacted a significantly (P < 0.05) lower soil pH (5.83) than the rest of the treatments while treatment B recorded the highest soil pH (6.58) in the pot experiment (Table 4) although not significantly different compared to the control, compost, compost + biochar. Further, no significant difference was

observed in soil pH among the treatments in the field experiment (Table 5). The total organic carbon and total nitrogen did not vary significantly among the treatments in the pot experiment whilst available P was significantly ($P < 0.05$). However, the CB treatment in the field experiment recorded the highest organic carbon content (1.54%) and was significantly higher than all the treatments. The effect of organic carbon indicates a decreasing order of B >C > Control. The total N concentration amongst treatments in the field experiment was not significantly different. There was no significant difference in soil available phosphorus concentration amongst the treatments in the pot experiment.

The treatments did not influence bulk density, soil moisture content and field capacity among the treatments. However, hydraulic conductivity (HC) was significantly increased amongst the treatment with NPK recording significantly ($P < 0.05$) higher (38.73 mm s^{-1}) than the rest of the treatments.

Effect of NPK, compost and/ or biochar on agronomic performance of cabbage.

Plant height

The effect of NPK, compost and/or biochar on plant height is shown in Figure 1 (pot experiment)

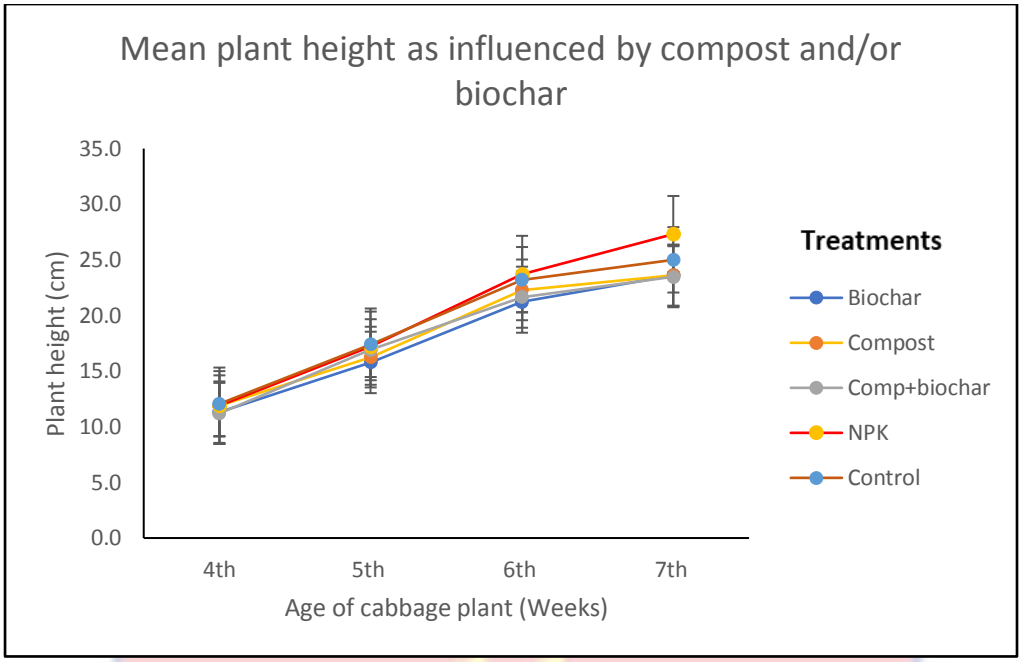

Figure 1: Mean plant height as influenced by NPK, compost and /or biochar from 4th to 7th week after planting (pot experiment).

The plant heights in the pot experiment were taken for four consecutive weeks. Plant heights measured during the 4th, 5th and 6th week of the experiment did not show any significant ($P > 0.05$) differences among the treatments. During the 7th week however, the NPK treatment showed a significantly higher plant height than the other treatments except the control (Figure 1).

The effect of NPK, compost and/or biochar on plant height is shown in Figure 2 (field experiment)

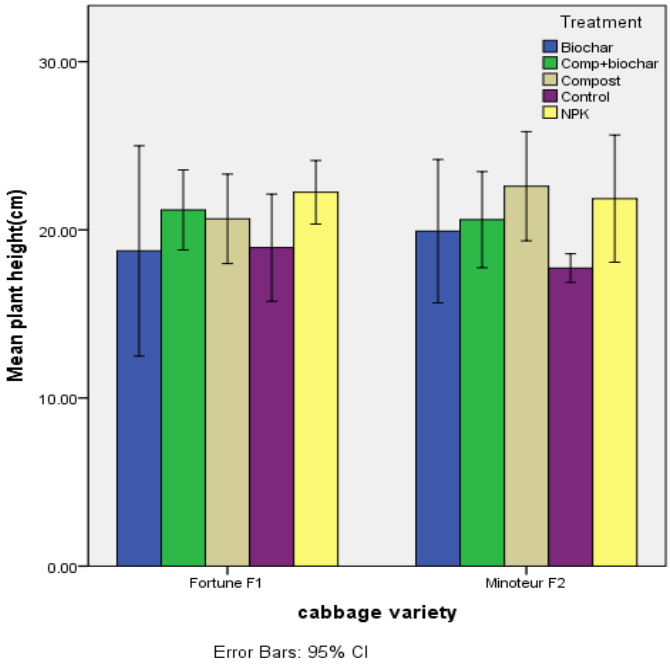

Figure 2: Mean plant height as influenced by NPK, compost and/or biochar at maturity (field experiment).

NPK treatment recorded the highest plant height, however this was not significantly higher from C and CB but recorded a significantly lower value from B and the control in the field experiment. The control recorded the lowest value of plant height on the field experiment (Figure 2)

Mean number of leaves per plant

The number of leaves per plant are shown in Figure 3 (pot experiment).

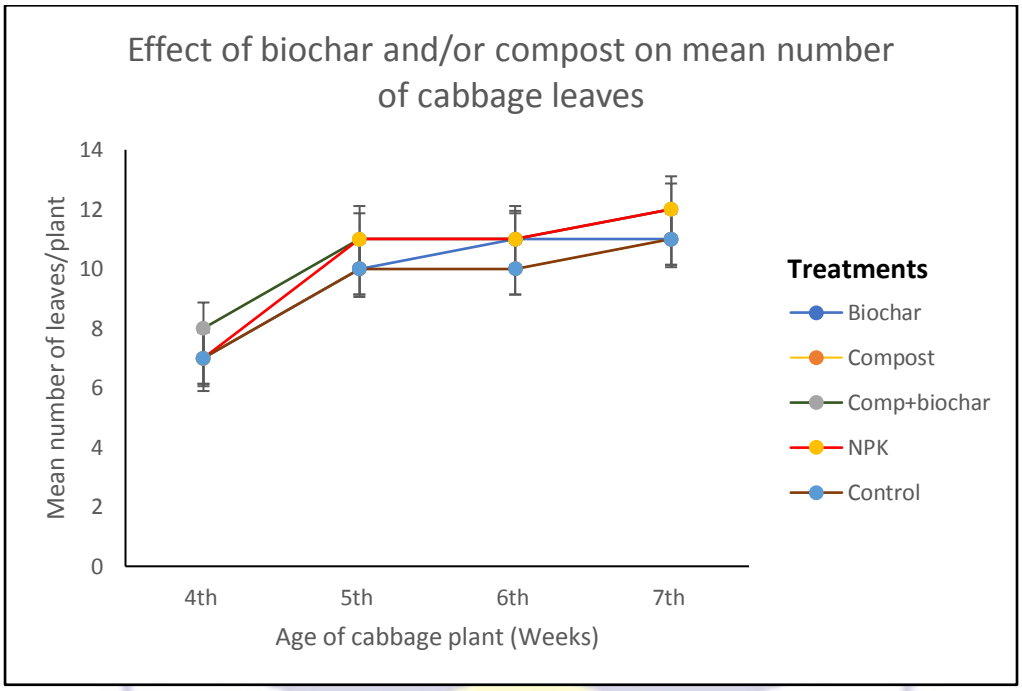

Figure 3: Effect of NPK, biochar and/or compost on number of cabbage leaves from 4 to 7 weeks after planting (pot experiment).

There was no significant ($P < 0.05$) difference in the mean number of leaves per plant among the treatments for the pot experiment (Figure 3).

The number of leaves per plant are shown in Figure 4 (field experiment).

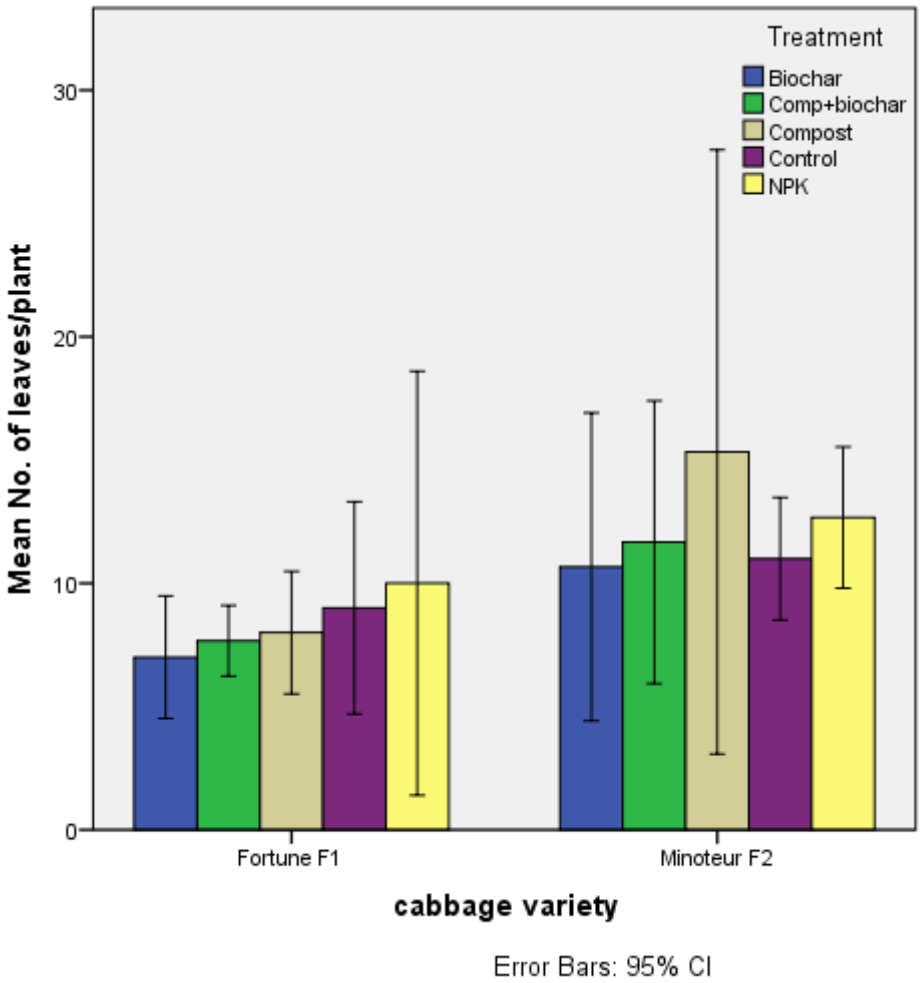

Figure 4: The effect of NPK, biochar and/ or compost on number of leaves maturity (field experiment).

At maturity the mean number of leaves per plant in the field experiment was not significantly ($P < 0.05$) different among the treatments (Figure 4).

Effect on NPK, compost and/or biochar on chlorophyll content index

The mean chlorophyll content index as affected by the treatment is shown in Figure 5.

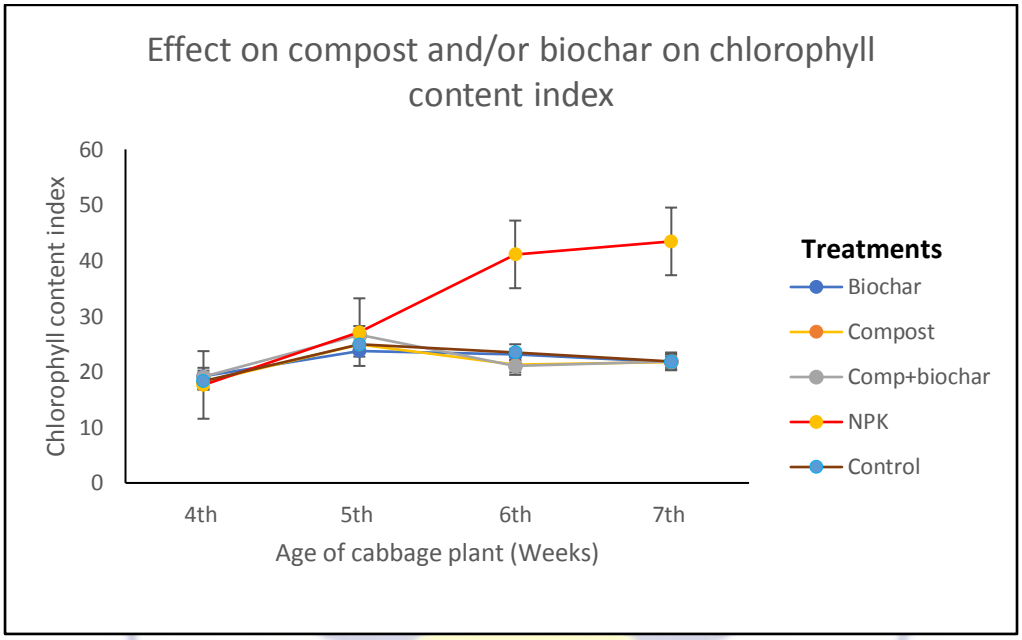

Figure 5: Effect on compost and/or biochar on chlorophyll content index

The chlorophyll content index did not differ significantly ($P > 0.05$) among the treatments in the 4th and 5th week of the experiment. At the 6th and 7th week however, the chlorophyll content index of the NPK was significantly ($P < 0.05$) higher than the rest of the treatment.

Effect of NPK, biochar and/or compost on aboveground and root biomass

The effect of treatment on aboveground and root biomass is presented in table 6 and 7.

Table 6: Mean effect of NPK, biochar and /or compost on aboveground and root biomass (pot experiment).

Treatment	Aboveground biomass			Root biomass		
	Fresh (g)	Dry (g)	% Moisture	Fresh (g)	Dry (g)	% Moisture
B (Biochar)	157.1	31.99	79.63	7.28	3.20	56.04
C (Compost)	164.3	31.17	80.84	8.34	3.04	63.87
CB (compost +biochar)	161.1	35.54	77.08	7.17	3.12	56.17
NPK	422.6	44.47	89.39	15.16	4.59	70.14
Control	150.3	28.94	80.59	7.05	2.97	59.00
P value	***	**	***	***	NS	NS
S.E. D	18.87	3.70	1.94	1.13	0.54	4.48

NS= not significant, *= significant at $P < 0.05$**= significant at $P < 0.01$, ***= significant at $P< 0.001$.

The fresh aboveground biomass from the NPK amended soil was significantly higher ($P < 0.05$) than the rest of the treatments in the pot experiment, however, the aboveground dry biomass from NPK amended soil was not significantly different ($P > 0.05$) from CB. Similarly, the cabbage from NPK treated soil was significantly ($P < 0.05$) higher in moisture than all the other treatments. NPK recorded significantly ($P < 0.05$) higher fresh root biomass than the rest. The dry weight and the moisture content of the root biomass however, did not vary significantly ($P > 0.05$) among the treatments (Table 6).

Table 7: Effect of NPK, biochar and /or compost on head, shoot and root biomass (field experiment).

	Mean yield of cabbage per plant (g plant $^{-1}$)									
TRT	Head			Shoots			Roots			
	Fresh (g)	Dry (g)	% M	Fresh (g)	Dry (g)	% M	Fresh (g)	Dry (g)	% M	Harvest Index (%)
B(biochar)	538.5	45.79	91.25	301.0	37.47	86.62	30.98	8.73	71.78	48
C(compost)	1135.0	73.95	93.23	454.0	60.42	86.76	40.22	9.83	74.83	52
CB(compost +biochar)	779.1	68.59	91.32	359.8	44.50	86.86	28.09	7.23	74.12	57
NPK	907.6	62.07	93.03	316.8	46.30	85.62	30.40	8.78	70.69	52
Control	223.2	20.47	91.18	274.6	50.02	82.34	26.83	6.40	74.31	35
P value	***	***	NS	*	NS	NS	NS	NS	NS	*

NS= not significant, *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P< 0.001.

Results from the field experiment indicated that treatment C recorded the highest fresh head biomass (1135 g plant^{-1}) but this was not significantly ($P > 0.05$) different from NPK (907.6 g plant^{-1}). The control treatment recorded the lowest fresh head biomass (223g plant^{-1}). The dry biomass of the cabbage head from the amendments NPK, C and CB were not significantly ($P > 0.05$) but were significantly ($P< 0.05$) greater than the control and treatment B. The moisture content of the treatments ranged from 91.2% to 93% in all the treatments. There was no significant ($P > 0.05$) difference in all shoot and root biomasses among the treatments for field experiments. Harvest indices was not significantly different ($P > 0.05$) amongst treatments B, C, CB and NPK, except control (Table 7).

Circumference of cabbage head

The mean circumference of the cabbage head at maturity is shown in figure 6.

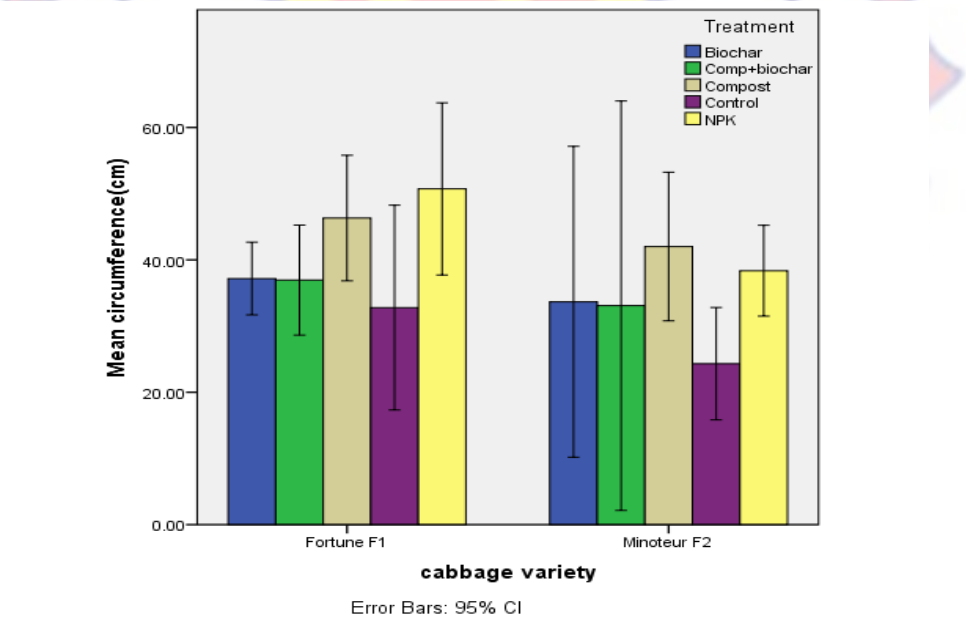

Figure 6: Effects of compost and/or biochar on circumference of cabbage head (field experiment)

NPK and C had a larger circumference and were significantly (P<0.05) different from the rest of the treatments. The control recorded the least value for head circumference (figure 6).

Effect of compost and/or biochar on plant nutrient concentration

The effect of the compost and/or biochar applied on plant nutrient concentration is summarized in Table 8.

Table 8: Plant nutrient concentration as affected by NPK, compost and/or biochar addition to soil (field experiment)

	Nitrogen (%)			Phosphorus (%)		
Treatment	Head	Shoots	Roots	Head	Shoots	Roots
B (Biochar)	3.13	2.19	2.33	0.54	0.36	0.85
C(Compost)	2.91	1.20	3.17	0.55	0.34	0.77
CB(compost +biochar)	2.37	1.98	2.36	0.50	0.35	0.74
NPK	3.36	2.23	3.20	0.62	0.33	0.72
Control	3.13	2.13	1.79	0.53	0.36	0.8
P value	***	NS	***	*	NS	***
S.E.D	0.16	0.10	0.22	0.03	0.01	0.02

NS= not significant, *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P<0.001. Means followed by the same letter in each column are not significantly different at P ≤ 0.05.

The NPK treatment recorded the highest N concentration in the cabbage though was significantly similar to treatments B, C and the control, but significantly higher than treatment CB. The N concentration in the shoots did

not show any significant levels among the treatments and between the varieties. N concentration in the NPK >and C of the cabbage roots was significantly ($P < 0.05$) higher from the rest. The control treatment recorded the least N concentration in root biomass. Cabbage head from the NPK amended soils was significantly higher in phosphorus than the rest except C. Biochar (B) amended soil recorded the highest P concentration in the root and was significantly ($P < 0.05$) different from the rest, except the control treatment (Table 8).

Effect of NPK, compost and/or biochar on nutrient (N and P) uptake by plant

The effect of NPK, compost and/or biochar on N and P uptake by plant is shown in Figure 7.

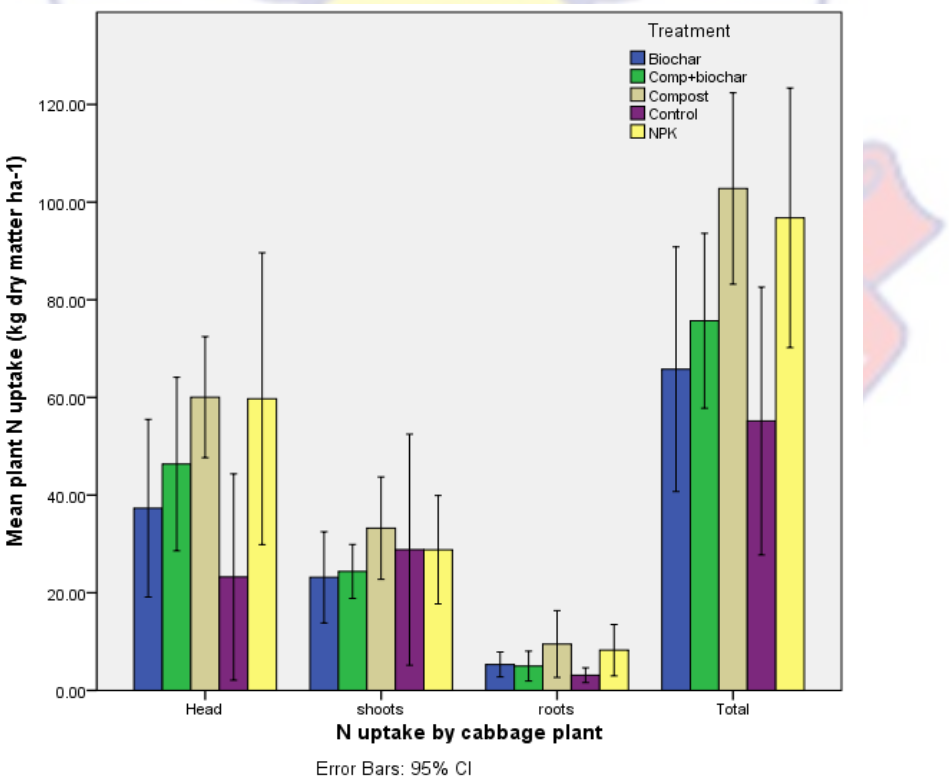

Figure 7: Effect of NPK, compost and /or biochar on N uptake by cabbage plant

Compost (C) and NPK amended soils had significantly higher ($P < 0.05$) N uptake in the cabbage head than the rest of the treatments except CB. The control treatment recorded the lowest N uptake value. There was no varietal difference amongst the treatments. There was no significant difference in N uptake by the shoots between the treatments and the cabbage variety. Nitrogen uptake by the roots was highest in treatments, although C was not significant compared to the other treatments. Control treatment recorded the least uptake. Total N uptake by the plant was higher in C >and NPK but was significantly higher from the rest except CB. The control treatment recorded the least N uptake (Figure 7).

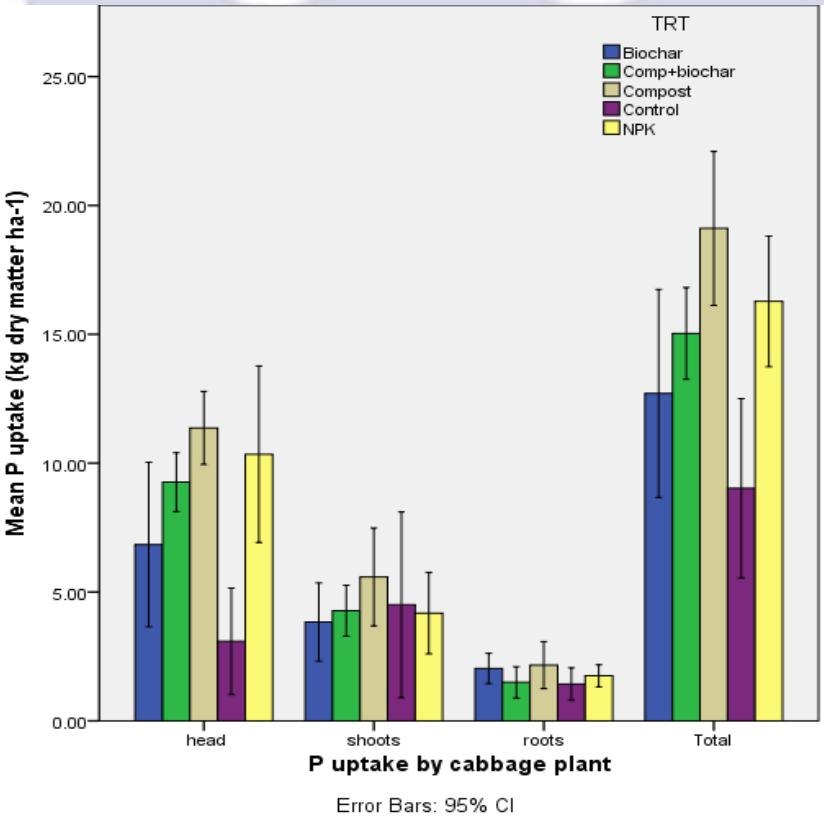

Figure 8: P uptake by cabbage plant as influenced by compost and/or biochar

Compost treated soil (C) recorded the highest P uptake by the head but was not significantly higher (P > 0.05) than the NPK, B and CB, except the control treated soil. The control treatment recorded the least uptake. Phosphorus uptake by cabbage shoots and roots was not significant (P > 0.05) different among the treatments. Compost treated soil recorded the highest total uptake of phosphorus by the plant but was not significant (P > 0.05) from NPK. The control recorded the least total P uptake (Figure 8).

Effect of compost and/or biochar on nutrient use efficiency (NUE).

The effect of compost and/or biochar on nutrient use efficiency is presented in table 9.

Table 9: Mean effect of treatments on agronomic efficiency (A.E), physiological efficiency (P.E), and Agro-physiological efficiency (A.P.E).

Treatment	Agronomic Efficiency		Physiological Efficiency		Agro-physiological Efficiency	
	N	P	N	P	N	P
B (Biochar)	7.82b	101.1c	4909a	199.3a	47.91ab	229.4
C (Compost)	13.51a	129.9ab	1152b	187.4ab	33.96ab	129.9
CB (Compost+ Biochar)	6.69b	143.8a	3639ab	212.0a	69.39a	303.8
NPK	12.84a	113.7bc	872b	159.5b	24.56b	469.7
Control	0.00	0.00	0.00	0.0	0.00	0.00
P value	0.001***	0.001***	0.025*	0.001***	0.015**	0.370
S.E. D	1.356	10.60	1500.0	18.0	17.42	406.7

*=significant at P < 0.05**= significant at P < 0.01, ***= significant at P<0.001. Means followed by the same letter in each column are not significantly different at P ≤ 0.0 5 using Fisher's Unprotected LSD.

Table 10: Mean effects of treatment on Nutrient use efficiency (NUE), nutrient efficiency ratio (NER) and apparent nutrient ratio (ANR)

Treatment	NUE		NER		ANR (%)	
	N	P	N	P	N	P
B (Biochar)	14.13b	17.66b	35.25b	185.9abc	23.12b	5.21b
C (compost)	18.67a	219.93a	34.93b	181.8bc	39.59a	88.62a
CB (compost+ biochar)	9.53c	23.43b	43.80a	205.4a	14.93b	7.59b
NPK	19.16a	28.74b	29.96c	165.5c	48.04a	12.10b
Control	0.00	0.00	32.97bc	191.5ab	0.00	0.00
P value	***	***	***	**	***	***
SED	1.67	5.65	1.86	10.11	6.41	3.60

= significant at P < 0.01, *= significant at P<0.001. Means followed by the same letter in each column are not significantly different at P ≤ 0.0 5.

Table 11: Correlation matrix between total N uptake and Nutrient use efficiency parameters

PARAMETER	TNU	AE	APE	PE	ANR	HI	NUE	NER
TNU								
AE	0.81 ***							
APE	0.18	0.27						
PE	-0.27	-0.09	0.25					
ANR	0.81 ***	0.95 ***	0.13	-0.22				
HI	0.38*	0.50*	0.36*	0.12	0.42*			
NUE	0.74 ***	0.93 ***	0.26	0.04	0.88 ***	0.56 **		
NER	hn	-27	0.18	0.64 ***	-0.46 **	0.33*	0.12	

*= significant at P < 0.05**= significant at P < 0.01, ***= significant at P<0.001. TNU: total nitrogen uptake, AE: agronomic efficiency, APE: agro-physiological efficiency, ANR: apparent nutrient recovery, HI: harvest index, NUE: nutrient use efficiency, NER: nutrient efficiency ratio.

Table 12: Correlation matrix of between P uptake and Nutrient use efficiency parameters

PARAMETER	TPU	AE	PE	NER	ANR	HI	NUE	APE
TPU								
AE	0.47**							
PE	0.38	0.73**						
NER	-0.18	0.39*	0.45					
ANR	0.64***	0.31	0.11	-0.11				
HI	0.22	0.18	0.25	0.35*	0.002			
NUE	0.64***	0.30	0.22	-0.02	0.95***	0.03		
APE	0.11	0.07	0.14	0.21	0.09	0.45**	0.10	

*= significant at P < 0.05**= significant at P < 0.01, ***= significant at P<0.001. TPU: total phosphorus uptake, AE: agronomic efficiency, APE: agro-physiological efficiency, ANR: apparent nutrient recovery, HI: harvest index, NUE: nutrient use efficiency, NER: nutrient efficiency ratio.

The nutrient use efficiency was measured to determine the effects of nutrient addition on the yield hence the control was omitted since no amendment was added. The parameters measured included agronomic efficiency (A.E), physiological efficiency (P.E), agro-physiological efficiency (A.P.E), nutrient efficiency ratio (NER), apparent nutrient recovery efficiency (ANR) and nutrient use efficiency (NUE). Compost (13.51) and NPK (12.84) treated soils recorded significantly (P < 0.05) higher A.E than B (biochar only) and CB (compost + biochar) with treatments (CB) recording the least (6.69). However, CB recorded the highest A.E (143.8) value for P but was not significantly (P >

0.05) different from C (129.9) but significantly higher A.E for P for treatment B. The P.E for both N and P were higher in B although similar to C and CB treatment. NPK amended soil recorded the least P.E but similar to C and CB treatment. A.P.E for N was significantly higher in CB than NPK which recorded the least (Table 12). The NPK treatment recorded the highest NUE value for nitrogen but did not vary from treatment C statistically ($P > 0.05$) with CB recording the least NUE. Treatment C was highly significant ($P < 0.05$) from the rest of the treatment for Phosphorus NUE. Biochar treated soil (B) recorded the least NUE. Compost +biochar (CB) treatment recorded significantly ($P < 0.05$) higher nitrogen NER from the rest of the treatments whiles NPK recorded the least nitrogen NER. Treatment CB recorded the highest NER for phosphorus but was not significantly different from the rest except NPK which recorded the least value. There were significant differences in ANR for N among the treatment with NPK and C significantly higher than B and CB. Sole compost (C) was significantly higher than rest in ANR recorded for phosphorus and sole biochar (B) recorded the least value. (Table 12).

Microbial population as influenced by NPK, compost and/or biochar

The effect of the compost and/or biochar applied on total microbial count is summarized in Table 13.

Table 13: Mean total viable aerobic count (log cfu) as influenced by the treatment and variety

Treatment	Microbial count (log/cfu)
Biochar	54.83a
Compost	26.33cd
Compost +Biochar	37.10bc
NPK	43.50
Control	23.33cd
P value	0.001***

***= significant at P < 0.001

There was significant difference (P < 0.05) in the total aerobic count (log cfu) among the treatment. Soil treated with only biochar (B) recorded the highest value (53.83) and was significantly higher (P < 0.05) than the rest. The control (23.33) recorded the least value (Table 13)

CHAPTER FIVE

DISCUSSION

Soil physiochemical properties

In the 10th week of the pot experiments, NPK application decreased soil pH by 0.43 units compared to the initial pH of 6.26 whilst the biochar and/or compost application increased the soil pH by 0.21 and 0.32 (Table 4a) respectively. The decrease in soil pH by the NPK treatment corroborated with findings of Palm et al (2011) who noted that inorganic fertilizer such as NPK accelerated soil acidification. The acidification of the soil is due to the rapid decomposition of SOM by chemical compounds from the NPK fertilizer which subsequently destroys the soil structure. On the contrary, biochar and all other treatments had a liming effect on soil in which it is incorporated (Ogutunde et al., 2004). Therefore, a combined application of biochar and compost significantly increased soil pH probably due the mineral ash content of the organic amendments which resulted in a liming effect raising the soil pH (Matsubara et al., 2002; Lehmann et al., 2003). Unlike the pot experiment, no significant differences in pH values were observed amongst treatments for the field experiment. The reasons for the disparity observed for treatments effects between the pot and field experiments is not clear.

The application of compost or biochar increased organic carbon in the soil in the field experiment. According to Frimpong et al., (2016), adding biochar and cow dung as a soil amendment improves physiochemical properties of soil and lettuce yield. The improvement in soil organic C, particularly in biochar amended soils could persist over a period of time. A study done by

Sukartono et al., (2011) indicated that when manure and coconut shell biochar were added to a sandy soil, organic C increased and remained high even after the second harvest. Fischer and Glaser (2012) and Rivero et al., (2004) also found that the addition of compost increased both organic carbon quality and quantity. The increase in organic carbon can be attributed to the carbon rich nature of biochar added to the soil (Lehmann et al., 2011). The relatively higher total N content in CB (compost +biochar) treatment in the field experiment after harvest could be due to the high initial N content of compost (Table 4b). The combined application of the biochar with the compost may have resulted in the N released from compost decomposition being absorbed onto the porous biochar surface to minimize leaching. Again the high pH of the amended soil contributed to the release of nitrogen and other available nutrient in the soil (Dadhawal et al., 2011). Adsorbed N would subsequently be slowly released for plant uptake (Reverchon et al., 2007; Cross & Sohi, 2011).

The higher phosphorus concentration in the NPK treatment of the pot experiment was probably due to the high pH of the biochar treated soil which makes phosphorous readily available owing to microbial activity in the soil (Lynch & Brown, 2001). Physical properties of the soil such as bulk density, soil moisture and field capacity were not significantly affected by the treatments possibly due to the short duration (4 months) of the experiment. The NPK treatment recorded the highest hydraulic conductivity value (38.73 mms^{-1}), an indication that the addition of inorganic fertilizer reduces water retention. Biochar treated soil (B), on the other hand recorded a lowest value (18.28 mms^{-1}) indicating that biochar addition increases soil water retention.

Biochar is known to increase water holding capacity in sandy soils and improve water use efficiency (Basso, Miguez, Laird, Horton, Westgate, 2013) and this could be attributed to its porous nature which makes it very effective at retaining both water and water-soluble nutrients. The hygroscopic ability of biochar thus makes it a desirable soil material in many locations due to its ability to attract and retain water (Jeffery et al., 2011; Sukartono et al, 2011, Sohi, Lopez-Capel, Krull, & Bol, 2009).

Agronomic performance of cabbage.

The results indicated that plants were relatively taller in the NPK plots treatment compared to the other treatments (Figure 1). The increased plant height found in the NPK amended soil could be attributed to the availability of nutrients as inorganic NPK fertilizer is readily soluble, thereby releasing nutrients easily following their addition to the soil (Chen, 2008). However, treatments did not show any significant effect on the number of leaves which depicts that biochar and/or compost does not influence leaf number of the cabbage plant. Minotta and Pinzauti, (1996) explained plant chlorophyll content is an indicator of photosynthesis. The chlorophyll index, which reflects the chlorophyll content of the cabbage plant was also significantly higher in the NPK treatment compared to the other treatments. Studies have shown that application of compost, biochar and inorganic fertilizer increases leaf chlorophyll in maize (Agegnehu et al., 2017). In this study, B (biochar only), C (compost only) and CB (compost +biochar) did not significantly increase leaf chlorophyll content probably due to the slow release of nutrients from organic amendments (Chen, 2008; Cross & Sohi 2011). The similarity in chlorophyll

content index amongst the treatments during the 4th and 6th week could be attributed to the fact NPK was not applied immediately after transplanting hence mineralization of N which results in a higher chlorophyll was realised in during the 6th and 7th week of the experiment.

Aboveground and root biomass

NPK treated plants had the highest fresh aboveground biomass (Table 6) due to the presence of N and P following the addition of inorganic fertilizer which make nutrients soluble and readily available for plant growth (Chen, 2008). Several studies conducted (Agegnehu, 2017; Mekuria et al., (2014); Major et al., (2010)) showed that increase in yield can be attributed to the availability of soil nutrients by inorganic fertilizer. Although the fresh aboveground biomass on NPK plots was relatively higher, the dry matter aboveground biomass of NPK and CB (compost + biochar) plants were similar. This is indicative that the nutrient availability and hence plant nutrient uptake in the compost + biochar treatment was similar to that in the NPK (Table 5).

Plant nutrient concentration

Increased in N and P concentrations in NPK plants points to the fact that inorganic fertilizer has a positive effect on plant biomass because mineral fertilizer easily soluble for plant uptake and utilization (Chen, 2008). Nitrogen fertilizer increased barley grain yield in a study conducted by Agegnehu Jenberu, (2017). Other studies by Petterson and Eckersten, (2007); Sinebo et al., (2004) also confirms this finding.

Nitrogen uptake by cabbage head and roots increased significantly in soils amended with organic fertilizer (compost) and inorganic fertilizer (NPK).

This attests to the fact that application of inorganic fertilizer easily makes nutrients available for plant use and this supports a work done by Stefano, Dris & Rapparini, (2004). Also, the combination of compost and biochar (CB) increased uptake to an appreciable amount (almost double of the control) but was lower than treatments with sole application of inorganic fertilizer (NPK) and compost (C) (Figure 5). This can be attributed to the adsorbing characteristic property of biochar. Biochar is known to adsorb nutrients and release it gradually for plant use (Trupiano, et al., 2017).

Similar to N uptake by cabbage head and roots, the increase in total P uptake by NPK and C treated plants could be related to the presence of readily available nutrients in the inorganic and organic fertilizer respectively. P uptake in CB was again lower compared to NPK and C which justifies biochar's ability to retain nutrients (Trupiano *et al*., 2017).

Nutrient uptake

Increased ($P< 0.05$) nutrient uptake for both N and P in C, NPK and CB treated plant could be due to the release of nutrients by both oragnic and inorganic fertilizer making it accessible for use by plants (Chen, 2008). Studies done by Agegnehu (2017); Inal et al., (2015); Lehmann et al., (200.
03) confirms that addition of organic fertilizer such as compost and compost + biochar improves plant P uptake and its availablity by reducing sorption and leaching. The significantly ($P < 0.05$) lower yield (223.2 g of fresh head plant $^{-1}$) and total N(55.15kg ha^{-1}) and P (9.03kg ha^{-1}) uptake in the soil without amendment (control) suggests why nutrient addition improves total uptake and result in higher yield (Figure 5).

Nutrient use efficiency

The significant increase (P>0.001) in A.E in C and NPK treated plants for N and P (Table 9 and 10) can be attributed to the application of the organic and inorganic fertilizer respectively which makes nutrients readily available for utilization by the plant. Although cabbage plants in NPK and C treatments performed better compared to sole application of biochar (B) and compost + biochar (CB), there was a significantly (P<0.05) higher A.P.E (which considers the shoots and head biomass) in the latter than NPK treated cabbage. This study indicates that addition of compost and biochar as soil amendment yields higher output compared to NPK and sole application of compost. A.P.E of P was however not influenced by the treatments. Biochar application increased P.E of both N and P and supports findings by Trupiano et al (2017) that sole application of biochar increases lettuce leaves number and total biomass.

The significant increase (P>0.001) in nutrient use efficiency (NUE) of nitrogen in C and NPK can be attributed to the readily available nutrient supplied by the organic and inorganic fertilizer which increase total N uptake by 102.72 kg ha^{-1} and 96.79 kg ha^{-1}, respectively. This finding indicates that NUE is directly influenced by nutrient uptake by the plant. The relatively low N uptake in CB (75.70 kg ha^{-1}) and B (65.78 kg ha^{-1}) explains why NUE in CB and B recorded lower values (Table 10). The low uptake in B and CB could be due to the fact that not all the nutrients were made available owing to the presence of biochar which has biphasic mineralization pattern (Cross & Sohi, 2011).

The increase in NER of N and P in CB (Table 10) shows that combined compost and biochar results in effective and efficient use of nutrients for maximum yield. Nitrogen and phosphorus availability from inorganic fertilizer and organic fertilizer resulted in the higher ANR in NPK (48.04%) and C (39.59%) respectively.

From the correlation matrix table (Table 11 and 12), total nutrient uptake for both N and P were positively correlated with NUE, AE and ANR. This explains why C, NPK and CB plants which had higher uptake values performed better than the control with relatively lower uptake.

Microbial Counts

The highest ($P < 0.05$) microbial count (54.53 log/cfu^6) was found in the sole biochar treatment. Applied biochar can improve soil microbial load due to its capacity to retain water and aerate the soil to create a conducive environment for microbial growth (Dempster et al., 2012). However, WHC data in the study did not vary among the treatments. The low microbial counts in the compost (26.33 log/cfu^6) amended soil could be attributed to other factors which (might inhibit microbial growth) was not considered in this research. Compost on the contrary increases soil microbial population (D'Hose *et al*., 2012).

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The use of inorganic fertilizer is expensive and usually not affordable to smallholder farmers and its long-term application also worsens the chemical and physical properties of soils. Organic fertilizers are often used as substitutes to inorganic fertilizers and such approach has been largely advocated for but insufficient nutrient levels of the latter and nutrient leaching of fertilizers makes the combine use of the two more recommendable. Inclusion of biochar in fertilizer management schemes to regulate the leaching of nutrients has been greatly recommended.

The study was conducted to explore the effect of combining compost and biochar on soil physiochemical properties and the yield of cabbage at both pot and field levels. Yield data was taken to elucidate which treatment influenced cabbage yield response best. The findings are expected to enable decisions on the appropriate amendment to increase cabbage yield whiles improving soil fertility for sustainable agriculture.

Conclusions

At the end of the study, the following conclusions were made:

1. Combined application of compost and biochar improved soil quality indices such as pH, organic carbon, and microbial activity of the soil.
2. Addition of compost and biochar resulted in an effective synchrony between N and P release from compost mineralization and crop uptake through temporarily N or P fixation on biochar surfaces leading to higher

N and P availability for crop uptake compared to sole application of biochar.

3. Combined application of compost and biochar resulted in a greater liming effects and hence higher P availability for uptake and improved cabbage yield compared to sole application of biochar.

Recommendation

From the study conducted, the following recommendations are proposed:

1. Further studies should be carried out on other crops with different application rates of biochar and compost to ascertain the economic efficient rate and recommend to farmers
2. Studies should be carried out on the economic implication on the use of biochar and compost against the conventional use of inorganic fertilizer
3. Future studies should be carried out to explain the long-term effect of compost and/or biochar on leaf chlorophyll content.

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APPENDICES

APPENDIX A

Effect of biochar and/or compost on soil physiochemical properties and cabbage variety

Treatment interactions	PARAMETERS							
	% soil N	% O. C	P ug g^{-1}	pH	% moisture of soil	H.C cm^{-1}	B.D g cm^{-3}	% moisture at field capacity
B+F	0.08	0.82	87.2	6.60	6.94	19.40	1.50	18.86
C+F	0.07	0.76	82.6	6.54	8.11	26.70	1.50	20.10
CB+F	0.16	1.69	116.6	6.66	5.76	25.40	1.51	19.80
NPK+F	0.10	1.04	110.9	6.45	8.63	35.30	1.49	20.35
Control+ F	0.06	0.73	88.4	6.20	8.68	23.40	1.58	19.00
B+M	0.09	1.60	183.1	6.56	8.44	17.10	1.57	19.06
C+M	0.08	0.91	119.9	6.42	6.81	21.30	1.47	21.68
CB+M	0.12	1.39	111.7	6.78	8.73	24.90	1.48	22.16
NPK+M	0.08	1.07	108.3	6.71	14.90	42.20	1.45	22.43
Control+ M	0.07	0.52	49.5	6.28	8.68	28.40	1.46	21.92
Lsd	0.07135	0.3873	86.18	0.6021	7.501	10.61	0.1817	5.784
F pr	0.702	0.006	0.216	0.887	0.659	0.412	0.645	0.962

B = Biochar, C =Compost, CB=Compost + Biochar, F= Fortune variety, M=Minoteur variety H.D= Hydraulic conductivity, B.D= Bulk Density, O. C= Organic Carbon

APPENDIX B

Effect of biochar and/or compost on Phosphorus content, uptake and cabbage variety

Treatment	% Phosphorus			Phosphorus uptake by plant(kg ha $^{-1}$)			Total P uptake (kg ha^{-1})
	Head	Shoots	Roots	Head	Shoots	Roots	
BF1	0.46	0.31	0.93	7.22	2.86	2.07	12.15
CF1	0.57	0.31	0.87	10.54	4.74	2.70	17.98
CBF1	0.53	0.33	0.81	9.20	4.35	2.02	15.56
NPKF1	0.57	0.31	0.71	12.41	3.36	1.80	17.57
ControlF1	0.52	0.35	0.79	4.64	2.91	1.75	9.30
BF2	0.63	0.41	0.76	6.46	4.81	2.0	13.26
CF2	0.54	0.36	0.66	12.19	6.42	1.63	20.24
CBF2	0.46	0.36	0.70	9.33	4.20	0.97	14.51
NPKF2	0.68	0.34	0.72	8.28	5.00	1.70	14.98
ControlF2	0.54	0.32	0.8	1.54	6.10	1.12	8.75
Lsd	0.0990	0.03713	0.07161	3.542	0.746	0.075	0.670
Fpr	0.014	0.003	0.001	0.141	3.657	3.074	6.276

B = Biochar, C =Compost, CB=Compost + Biochar, F= Fortune variety,

M=Minoteur variety

APPENDIX C

Effect of biochar and/or compost on nitrogen content, uptake and cabbage variety

Treatment	% Nitrogen			Nitrogen uptake by plant(kg ha $^{-1}$)			Total N uptake (kg ha^{-1})
	Head	Shoots	Roots	Head	Shoots	Roots	
B+F	2.52	2.01	3.70	38.0	18.7	8.57	65.3
C+F	2.30	1.92	4.21	46.4	29.2	13.34	89.0
CB+F	2.25	1.78	3.73	37.2	23.8	9.33	70.3
NPK+F	3.23	2.06	4.03	78.9	22.2	10.49	111.6
Control +F	2.89	2.12	1.84	40.0	18.0	4.61	62.6
B+M	3.78	2.37	0.95	36.6	27.7	2.05	66.3
C+ M	3.52	2.08	2.13	73.7	37.3	5.66	116.6
CB +M	2.49	2.17	0.99	55.5	25.0	0.61	81.1
NPK+M	3.40	2.41	2.37	40.5	35.4	6.00	81.9
Control +M	3.37	2.13	1.73	6.4	39.7	1.62	47.7
Lsd	0.4784	0.3022	0.6776	22.87	23.83	3.074	36.06
Fpr	0.005	0.292	0.001	0.001	0.764	0.075	0.194

B = Biochar, C =Compost, CB=Compost + Biochar, F= Fortune variety,

M=Minoteur variety

APPENDIX D

FIELD EXPERIMENT

Effect of biochar and/or compost on agronomic efficiency, physiological efficiency, Agro- physiological efficiency and cabbage variety

Treatment	Agronomic Efficiency		Physiological Efficiency		Agro-physiological Efficiency	
	N	P	N	P	N	P
B+F	7.87	99.8	8061	2535	55.5	442
C+F	9.85	101.9	2516	193.7	32.7	-30
CB+F	4.87	98.1	5121	191.9	54.3	321
NPK+F	15.87	115.5	1862	181.1	21.4	-2
Control+ F	0.00	0.00	0	0	0.00	0.00
B+M	7.77	102.4	1758	145.0	40.3	17
C+M	17.17	157.9	-212	181.1	35.2	354
CB+M	8.50	189.4	2157	232.0	84.5	287
NPK+M	9.82	118.8	-119	137.8	27.7	-937
Control	0.00	0.00	0 .00	0	0.00	0.00
Lsd	4.103	32.09	45.40	54.49	52.72	1231.2
P Fr	0.002	0.001	0.138	0.013	0.769	0.589

APPENDIX E

Effect of biochar and/or compost on nutrient use efficiency, nutrient efficiency ratio, apparent recovery efficiency and cabbage variety.

Treatment	Nutrient Use Efficiency		Nutrient Efficiency Ratio		Apparent Recovery Efficiency (%)	
	N	P	N	P	N	P
B+F	17.47	20.9	41.80	213.3	18.8	1.1
C+F	16.66	211.9	42.13	177.0	22.1	70.8
CB+F	9.51	20.8	47.87	188.0	11.4	0.9
NPK+F	24.32	37.1	31.22	178.3	64.4	18.1
Control +F	0	0	35.04	193.4	0	0
B+M	10.79	14.4	28.69	158.6	27.7	11.5
C+M	20.68	227.9	27.74	186.6	57	106.5
CB+M	7.54	26.1	39.74	222.8	18.4	14.3
NPK+M	13.99	19.7	28.70	152.8	31.7	6.1
Control+ M	0.00	0	30.90	189.6	0.0	0.0
Lsd	5.063	17.09	5.635	30.61	12.95	10.90
P Fr	0.006	0.083	0.021	0.005	0.001	0.001

APPENDIX F

Chlorophyll content determination using CCM 200 plus (Apogee intrument)

APPENDIX G

Application of soil amendment

APPENDIX H

Cabbage seedling at the nursery