UNIVERSITY FOR DEVELOPMENT STUDIES

ASSESSMENT OF THE EFFECT OF CARBONIZED AND UNCARBONIZED COMPOST BASED AMENDMENTS ON SOIL PROPERTIES, NUTRIENT UPTAKE AND YIELD OF FRESH MAIZE

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY FOR DEVELOPMENT STUDIES, GHANA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY (MPHIL) HORTICULTURE

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CANDIDATE'S DECLARATION

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

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SUPERVISOR'S DECLARATION

I 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 for Development Studies.

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ABSTRACT

A field experiment was conducted in 2015 at Gumbihini, an open space market gardening site in Tamale Ghana. The objective of the study was to determine the effects of carbonized and uncarbonized compost based soil amendments on changes in soil properties, nutrient uptake, growth and yield of fresh maize. Six compost treatments were made with poultry manure (15%vol), rice straw (60%vol) and either amended with carbonized rice huskcompost, carbonized corn cobcompost and carbonized wood or their uncarbonized feedstock. This then gave six treatments and consisted of uncarbonized rice husk compost (R_0), uncarbonized corn cobs compost (M_0), uncarbonized sawdust compost (S_0), carbonized rice husk compost (R_1), carbonized corn cobs compost (M_1) andcarbonized wood compost (S_1). The experiment also included two other conventional composts which were sawdust multi-grow compost (G_1) and rice husk multi-grow (G_2) with two other controls (NAP and CO). Treatments were arranged in Randomized Complete Block Design (RCBD) with four replications. Data was collected on growth parameters, above ground biomass, soil properties, nutrient uptake and mass loss of compost in litterbags. The experimental results showed significant differences ($P > 0.05$) in stem girth, fresh yield (Stover), dry biomass. The results also showed that both carbonized and uncarbonizedcompost application significantly increased soil pH and increased the levels of C, N, and P in the topsoil. There was significant difference in mass loss of the composts after three months and one year of incorporation of the litterbags in soil. Further knowledge should be obtained

about the long-term effects of compost on soil properties and plant performance.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The livelihood of many people in Northern Ghana is largely dependent on agriculture which is limited by poor soils. The soils of are inherently low in cation exchange capacity (CEC) and have low buffering capacity (Anane-Sakyi*et al*., 2005). These soils have been subjected to severe nutrient mining, organic matter depletion and application of inorganic fertilizers which results in acidification, erosion and moisture depletion. Farmers therefore resorted to the use of compost amendments to boost soil quality and improve crop yield.Compost is explained as stable aerobically decomposed organic matter which results from a controlled decomposition process (Nguyen, 2016; Beyer *et al.,* 2002).The importance of compost amendments to soil therefore include pH stabilization and faster water infiltration rate due to enhanced soil aggregation (Bulluck *et al.,* 2002; Stamatiadis *et al.,* 1999). Some agronomic reasons for the use of compost include increased crop productivity, reduced fertilizer and pesticide use (Schulz et al., 2013).Therange of environmental benefits of compost application includes improved soil health, water savings and environmentally friendly way of waste disposal (Millner*et al.,* 1998). Compost has more advantages than other organic amendments because of reduced volumes and slower decomposition rate and absence of pathogens (Nguyen, 2016).

Application of compost alone to soils is still subject to leaching losses, gaseous emissions andwider carbon – nitrogenratio (C:N) which is most critical for N availability to plants (Steiner *et al.,* 2008).It has been reported that N availability can be a limiting factor for soil microorganisms responsible for decomposition of organic material (Mary *et al.,* 1996). When organic materials having wideC:Nratio undergoes microbial decomposition, the soils can become N limited (Beyer *et al.,* 2002). Additional N can come from mineralN or added N fertilizer. Thus availability of applied N to plants couldreduceas a result of application of poorly composted materials with higher C:N ratios(Aziz *et al.,* 2010).The application of organic amendments to soil can stimulate N uptake (Jones *et al.,* 2007). Finished compost is generally more concentrated in nutrients, narrow in C:N ratio and also effectively free from other un-desirable characteristics (Zia *et al.,* 2003). However, incorporation of appropriate rate of urea-N can reduce the quantity of applied organic waste substantially. Moreover, whenever organic material containing high amount of nitrogen is applied to the soil, less amount of the originally applied organic material is decomposed/lost thus more added to the soil (Kolay, 2000).

The application of biochar (carbonized biomass) is known to prevent nutrient losses but will not improve soil properties holistically because it is limited critical nutrients such as nitrogen (Erhart&Hartl, 2010). Combining compost and carbonized biomass could be used to obtain the benefits of nutrient addition and retention in soils.Leaching can also be an important factor in N losses from compost, depending on rainfall conditions (Eghball*et al., 2002*). Due to gaseous losses of C and N during the composting process, and retention of heavy metals, the concentration of heavy metals in composts are often higher than soil and can therefore increase soil concentrations when used as a sole amendments (Smith, 2009). Therefore, co-composting carbonized and uncarbonized biomasses can reduce nutrient losses and accumulation of heavy metals in the soil.

Biochar (carbonized)is explained as a carbonaceous porous material obtained by pyrolysis of biomasses, and may offer the chance to adsorb and retain plant nutrients and improve soil fertility(Nguyen, 2016). A number of benefits have been documented with biochar amendment to soils, including increased water holding capacity (WHC), reduced bulk density, liming effects and reduced N leaching(Kammann *et al.*, 2015).

Co-composting on the other hand is the controlled aerobic degradation of organic materials, usually more than one feedstock (carbonized and uncarbonized). By combining compost and biochar, the benefits of each can be used to optimize the process and the product. Despite several studies on compost-biochar mix for field application, very little or none has examined the carbonization of biomass during the composting process.

1.2 Problem Statement

Soils of Northern Ghana are known to be poor in nitrogen, phosphorus and poorly structured with low organic matter content and low water holding capacity. Soil nutrient depletion and declining agricultural productivity are creating huge yieldgaps and threatening the sustainability of agricultural systems in Sub-

Saharan Africa, especially northern Ghana (Parry, 2007; Pender, 2009). Over the years, farmers have relied on inorganic fertilizers to boost plant growth and yield in Ghana. However, the use of inorganic fertilizers has been reported to result in severe soil acidification and nutrient unavailability. The continuous use of inorganic fertilizers has also been reported to cause nitrate leaching into water bodies and eutrophication (Evanylo*et al*., 2008). Application of composted crop residues has been reported to improve soil properties and could bridge the yield gaps of soils especially under acidic conditions (Kammann*et al*., 2015).The current proliferation of compost is possibly due to its role in maintaining and improving 'soil health', as well as the increased demand of consumers for organically produced food(Schulz *et al*., 2013). With growing the food, bio-energy and bio-material demands, new agricultural strategies are required to reduce the environmental costs of agricultural production.

Recent studies have indicated that applications of composted residues are still subject to nutrient losses through leaching and gaseous emissions (Strauss *et al*., 2003; Evanylo*et al*., 2008). Thus, to mitigate global warming and adapt to future hazards (e.g. more massive rainfall events and severe droughts), agricultural practices are therefore required to reduce N losses for a more effective N fertilizer use, and at the same time promote soil organic carbon (SOC) accumulation in soil(Simunek, 2014). Soil amendment with pyrogenic carbon (Biochar) is discussed as strategy to improve soil fertility to enable economic plus environmental benefits. Composting usually leads to high N losses by NH_3 and eventually N_2O emissions. Carbonization of biomass produces carbon rich material which is resistant to microbial degradation and has the potential to prevent leaching losses and gaseous emissions. Addition of biochar-compost mixtures is supposed to reduce N losses during composting(Steiner *et al*., 2008).

The cumulative loss of organic matter increased with composting time in all types of composts and also measured in the form of weight loss. The weight loss or organic matter loss was found highly correlated with C:N ratio and other maturing parameters (Chefetz*et al.*, 1996; Raj and Antil, 2012). The incorporation of maturedcompost to soil can enhance soil fertility by improving physical, chemical and biological properties of the soil (Anwar *et al., 2015)*. The physical changes involve modifications of soil bulk density, structure, strength and water relations. The chemical changes include the accumulation of organic plant nutrients, the cation exchange capacity, chelating activity and buffering ability (Anwar *et al.*, 2015). Plant growth significantly increased with co-compost amendment (Schulz *et al.*, 2013). Use of organic amendment has substantially increased mainly, because of sustained crop production, awareness about foodquality and increased cropping intensities(Aziz *et al.*, 2010).

Sustainable agriculture faces constraints due to low nutrient status and rapid mineralization of soil organic matter (Zech*et al.*, 1997). There has been little work on the impact of organic amendments in combination with biochar on plant growth and yield (Lashari*et al.*, 2015).An alternative is the use of co compost of different feedstock. By combining the two, the benefits of each can be used to optimize the process and the product. Many studies are now focused on co-application of compost and carbonized biomass to optimized N and C balances which are critical for promoting and sustaining yields in poorly structured acid soils (Simunek, 2014; Schulz *et al.*, 2013). However, there has not been any comprehensive study to determine the effect of co-composting of carbonized biomass and its subsequent application on soil properties, nutrient uptake and crop yields.

1.3 Objectives

i. To determine change in soil properties under carbonized and uncarbonized compost amendments.

ii. To determine the growth and yield of maize under carbonized and uncarbonized compost amendments.

iii. To determine the effect of carbonized and uncarbonized compost amendments on nutrient uptake.

iv. To determine the decomposition rate and nutrient stability under carbonized and uncarbonized compost amendments.

1.4 Justification of the study

This study would enrich the stock of existing but limited knowledge and literature whose focal point is on composting and it application by farmers in sub-Saharan Africa and thus serve as a reference material for policymakers, academicians and researchers. Most importantly, this study can give a better insight into the role of compost in enhancing plant and soil health, increasing food security and reducing poverty as a whole.

1.5 Organizational plan of the Study

The study is organized in six chapters. Chapter one deals with the background to the study, statement of the problem, objectives of the study, justification of the study and organizational plan.

The relevant literature review is presented in chapter two whilst chapter three deals with the methodology. Chapter four focuses on data presentation; chapter five is discussion of result whereas chapter six consists of summary of key findings, implications of findings, conclusion, recommendations and areas for future research.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter reviews literature on compost history and definition, composting process and phases, and risk of composting. A section of the chapter reviews literature on compost benefits and its effects on soil properties. Another section is devoted to effect of compost on plant growth and development, nutrient uptake, and crop N uptake. Literature on biochar, soil chemical and physical parameters has been reviewed. The final section reviews literature on compost maturity and stability and it assessment process.

2.2 Compost definition

A scientific concern is the massive generation of organic waste by human activities, which has generated various alternatives to avoid landfilling and promote recycling and for which composting is one of the best-known and well-established processes(Martínez-blanco, 2013). Composting allows the stabilization and management of organic waste through accelerated aerobic decomposition under controlled conditions, resulting in a product called compost. Several studies indicate that, the use of compost on land may improve several growth and soil parameters, which would make compost an interesting option for soil restoration purposes (Martínez-blanco *et al.,* 2013). Addition of compost to soil, increases soil organic matter content, enhances aggregation and stability, thereby ameliorating soil structure (Diacono and Montemurro, 2010). Stability of soil aggregates prevents surface sealing, improves water infiltration, and enhances water holding capacity, thus reducing runoff generation and soil erosion.

Compost is defined as stable aerobically decomposed organic matter (Paulin and Malley, 2008). FAO defines composting as the mixture of organic matter (digested aerobically) used to improve soil structure and provide nutrients (Pilar *et al.*,2015). The composting process is based on aerobic microbial breakdown which transforms organic materials into a variety of complex organic molecules. Compost is usually dark brown and has an earthy appearance and smell(Paulin and Malley, 2008).

2.1.1 Composting process

Composting is referred to the biodegradation process of a mixture of organic substrate by bacteria, actinomycetes and fungi (Insam and Bertoldi, 2007). These microbes attack, feed on and digest organic wastes, then these micro-organisms are preyed upon by the second level of organisms, e.g. protozoa and beetles, mites. Finally, centipedes and ground beetles consume the second level organisms (Pilar *et al.*, 2015).Composting differs from other decomposition systems because temperature and rate of decomposition are controlled (Bernal *et al.,* 1998). Composting provides the chance to safely transform organic waste into inputs for agricultural production. However, not all materials that have been transformed aerobically are considered compost.

2.1.2 Factors of the composting process

The most important factor of the composting process is the diverse population of predominantly aerobic micro-organisms. Their activities depend on the C:N ratio, O_2 supply, moisture content, temperature, particle size and pH of the compost heap (Mohee, 2007).

Micro-organisms need 30 parts of C for each part of N, where 20 parts are oxidized to carbon dioxide (CO_2) for energy and 10 parts are used in the syntheses of protoplasm (Sunar*et al.,* 2009). N is used as a source of protein for cell production and population growth. A C:N ratio between 20:1 to 35:1 leads to an efficient process, but a ratio of 30:1 is optimal. When the C:N ratio rises above this level, meaning there is an inadequate N supply, heat production drops and the rate of composting slows down. On the other hand, when the C:N ratio drops below 20:1, excess N is lost as ammonia gas (NH_3) and there is a rise in pH, which may be toxic to some micro-organisms. During the composting process, the C:N ratio of the initial material typically declines because the C is oxidized and the N is mineralized by micro-organisms (Mohee, 2007; Hubbe*et al.,* 2010).

Bacteria, fungi and actinomycetes prefer different types of organic material and when these organic substances are no longer available, they become dormant or die. Microbial activity is optimal when pH ranges between 6.5 and 8. However, bacteria need a pH between 6 and 7.5 whereas fungi need a pH between 5.5 and 8.9 for their activities. The pH varies with the raw material used in the compost and the production of various products (lactic and acetic acids) during the composting period. During the thermophilic stage, pH can rise up to 9 and thereby releasing NH_3. In the maturation stage, pH will drop to neutral (Mohee, 2007; Hubbe*et al.*, 2010).

Composting is an aerobic process, so micro-organisms require O_2 to break down the organic materials. Therefore, there should be enough void space to allow movement of O_2 from the atmosphere into the heap and allowing CO_2 and other gases to go out. The O_2 concentration is related to the different microbial populations and gasses in the compost heap, like O_2, NH_3, H_2S and CO_2 (Sunar*et al.*, 2009). Micro-organisms can only digest organic material if the compost heap has moisture content between 50 and 60%. This will provide a thin layer of moisture around the organic material, while still allowing free air movement. Water is produced during the compost process by the micro-organisms and is lost by evaporation. In the tropics, temperatures are high and compost can quickly dry out. Therefore, farmers need to ensure an adequate moisture content at all times by wetting the mixture initially and if necessary during the process as well(Hubbe*et al.*, 2010).

2.1.3 Composting phases

Composting is a biological process that occurs under aerobic conditions (presence of oxygen). Composting can be interpreted as the sum of complex metabolic processes performed by different microorganisms that, in the presence of oxygen, use nitrogen (N) and carbon (C) available to produce their own biomass. In this process, additionally, the microorganisms generate heat and a solid substrate, with less carbon and nitrogen, but more stable substrate, called compost (Pilar *et al.*, 2015). Upon decomposition of C, N and all initial organic matter, microorganisms release measurable heat through temperature variations over time. Three main phases in composting can be identified depending on the temperature produce during the process. The composting process has 3 stages; a rapid stage of decomposition, stabilization and humification(Insam and Bertoldi, 2007). The different phases of composting are divided according to temperature into mesophilic, thermophilic, cooling and maturation phases.

2.1.3.1 Mesophilic phase

The composting process starts at ambient temperature and in a few days (or even hours), the temperature rises to about 45°C (Pilar *et al.*, 2015). Mesophilic bacteria are predominant and the temperature in the compost pile increases to between 35^{o}C - 45^{o}C (Sunar *et al.*, 2009). The temperature increase is due to microbial activity since, in this phase, the microorganisms use C and N sources generating heat. Decomposition of soluble compounds, such as sugars, produces organic acids and hence, pH can drop (to about 4.0 or 4.5). This phase lasts a few days between two to eight days (Hubbe*et al.*, 2010).

2.1.3.2 Thermophilic and hygienization phase

When the temperature exceeds 45^{o}C mesophilic bacteria are replaced by thermophilic bacteria (Pilar*et al.*, 2015;Sunar*et al.*, 2009;Hubbe*et al.*, 2010). When the parent material reaches temperatures higher than 45°C, the micro-organisms that develop at average temperatures (mesophilic micro-organisms) are replaced by those that grow at higher temperatures, mostly bacteria (thermophilic bacteria) that facilitate degradation of complex sources of C, such as cellulose and lignin (Pilar *et al.*, 2015; Sunar *et al*., 2009;Hubbe *et al.*, 2010). These micro-organisms act transforming nitrogen into ammonia, so the average pH rises. At 60°C, bacteria producing spores and actinobacteria which are responsible for breaking down waxes, hemicellulose and other compounds of C complex, begin to develop. This phase can last from days to months, depending on the parent material, climatic and site conditions, and other factors. This phase is also called hygienization phase since the heat generated destroys bacteria and contaminants of faecal origin such as *Escherichia coli* and *Salmonellaspp*(Insam and Bertoldi, 2007).

2.1.3.3 Cooling or mesophilic phase II

The increase in activity of the thermophilic leads to an increase in temperature up to 70^{o}C when the substrate is depleted, the overall microbial activity decreases, the temperature falls (cooling stage) and the compost enters the maturation stage (Pilar*et al.*, 2015). Once carbon and nitrogen sources in composting material are exhausted, temperature drops again to about 40-45°C. During this phase, polymers degradation as cellulose continues and some fungi visible to the naked eye appear. Below 40°C, mesophilic organisms resume their activities and pH of the medium decreases slightly while, in general, pH remains slightly alkaline. Some fungi can develop and even produce visible structures. This cooling phase requires several weeks and may be confused with the maturation phase

2.1.3.4 Maturation phase

This phase lasts months at ambient temperature, during which side reactions such as carbonaceous compounds condensation and polymerization occur to form humic and fulvic acids(Pilar*et al.*, 2015).

2.1.4 Risk of composting

The use of a material that has not successfully completed the composting process (raw or only stabilized) can lead to risks such as phytotoxicity, Nitrogen starvation, root oxygen reduction, excess ammonium and nitrate in plants and contamination of water(Pilar*et al.*, 2015; Insam andBertoldi, 2007).

2.1.4.1 Phytotoxicity

In a material that has not finished the composting process adequately, nitrogen is in the form of ammonium instead of nitrate(Pilar *et al.*, 2015). Ammonium in hot and humid conditions is transformed into ammonia, creating a toxic environment for plant growth, resulting in odours. Similarly, unfinished compost contains unstable volatile chemicals such as organic acids that are toxic to seeds and plants(Motsara and Roy, 2008;Mohee, 2007).

2.1.4.2 The Biological block of nitrogen (Nitrogen starvation)

Nitrogen Starvation occurs in materials that have not reached a balanced C:N ratio and are far richer in carbon than in nitrogen. When applied to soil, micro-organisms quickly use them C present in the material increasing the consumption of N and exhausting the reserves of N(Pilar *et al.*, 2015).

2.1.4.3 Root Oxygen reduction

When material in the decay phase is applied to soil, microorganisms will use the oxygen of the soil to continue the process, exhausting it and not making it available to plants (Pilar *et al.*, 2015;Mohee, 2007)

2.1.4.4 Excess ammonium and nitrate in plants and contamination of water resources

A decaying material with excess nitrogen in the form of ammonium tends to lose it by infiltration into the soil or volatilization and contributes to contaminate trickling and underground water. Likewise, it can also be taken by the crop, producing an excessive accumulation of nitrates, with negative consequences on the quality of fruit and human health(Ghosh *et al.*, 2015; Mohee, 2007).

2.2 Benefits of compost

Compost plays a crucial role in maintaining soil functions and is a parameter for soil fertility and resistance to erosion. The build-up in the soil is a slow process, much slower than its decline and can be enhanced by farm management techniques. Examples of these techniques are: zero tillage, organic farming, maintenance of permanent grassland and cover crops, mulching, manuring with green legumes and application of farmyard manure and compost (Martínez-blanco *et al.,* 2013). If soils have inadequate amounts of organic matter (OM), they may not hold enough water and cannot ensure a favorable environment for beneficial micro-organisms. These soils become quickly dependent on high levels of watering, multiple fertilizer applications and pesticides (Stan *et al*., 2009). Therefore, soils containing less than 2% OM benefit from management strategies that will increase OM (Martínez-blanco *et al.*, 2013). Compost improves soil organic matter and hence improving physical, chemical and biological functions of the soil (Aziz *et al.*, 2010).

2.2.1 Physical functions

Compost enhances aggregation and stability and thereby improving soil structure and soil porosity. Stability of aggregates prevents surface sealing and soil erosion, improves water infiltration, and enhances water holding capacity (Martínez-blanco *et al.*, 2013). Soil porosity is important for root proliferation, gas exchange, and water retention and movement. Moreover soil organic matter (SOM) improves the retention of plant nutrients and increases the soil biodiversity (Mwiti*et al.*, 2012).

2.2.2 Chemical functions

Compost is a source of plant nutrients, especially in the direct supply of N, P, S and K. Organic inputs also enhance cation exchange capacity (CEC) particularly in sandy soils and reducealuminium toxicity and P-fixation in strongly acid soils with oxide mineralogy.Many scientist have reported a significant increase of organic C with the application of compost as compared to inorganic fertilizers(Erhart and Hartl, 2010; Diacono and Montemurro, 2010; Mwiti *et al.*, 2012). Compost has an impact on mineralization rate by increasing soil C directly, whereas inorganic fertilizers increase C only indirectly by improving plant growth (Erhart and Hartl, 2010).

2.2.3 Biological functions

Compost stimulates the activities of macro-fauna and micro-organisms in the soil and contributes to the nutrients release. The micro-organisms require N for their growth, so they break down the organic materials and release nutrients. This process involves immobilization of N from the soil by the micro-organisms (Mwiti *et al.*, 2012).

2.3 Effects of compost on soil properties

2.3.1 Physical properties

The benefits of compost application on soil physical properties are the reduction of soil bulk density and the increment of total porosity. Soil bulk density and total porosity are likely to improve as a result of the low bulk densityand high organic matter content of the compost(Stan *et al.*, 2009). Compost can also increase soil water holding capacity (Curtis and Claassen, 2005).Further, soil structural stability aggregate formation is improved by compost application (Tejada*et al*., 2009).

2.3.1.1 Water holding capacity

Water holding capacity of soils provides available water to plants and also helpin resistance to drought. In a more structured soil, changes in both aggregation and pore size and continuity may affect the water holding capacity. Compost produced from urban waste was reported to increase soil water holding capacity when applied(Tejada*et al.*, 2009). Urban waste compost has also been shown to increase total porosity (Aggelides and Londra, 2000;Tejada*et al*., 2009). Porosity is a measure of the size and arrangement of voids in the soil matrix, and thus affects both aeration and water movement (Nguyen, 2016).

2.3.1.2 Bulk density

Aggelides and Londra (2000) reported that the amendment of soil with compost improved all physical soil properties and the improvement was proportional to the compost rate.The bulk density of the soil usually decreases by supply of organic matter (Stan *et al.*, 2009). Other significance of compost application on soil physical properties is reduced bulk density and increased total porosity. The magnitude of change for bulk density and other soil properties is likely to differ with soil texture.It is noted that compost decreased penetration resistance in the subsoil under potatoes, possible indicating improved soil structure (Aggelides and Londra, 2000;Tejada*et al*., 2009).

2.3.2 Chemical properties

2.3.2.1 pH

Soil pH is one of the most frequently performed determinations and is one of the most indicative measurements of soil chemical properties (Motsara and Roy, 2008). Soil pH tells more about a soil than merely whether it is acidic or basic. It also indicates the availability of essential nutrients, and toxicity of other elements can be estimated because of their known relationship with pH (Motsara and Roy, 2008). Soil pH is affected by many factors which include nature and type of inorganic and organic matter, the amount and type of exchangeable cations and anions, soil: solution ratio, salt or electrolyte content, and CO_2 content (Ganjali*et al.*, 2013;Motsara and Roy, 2008). The acidity, neutrality, or basicity of a soil influences the solubility of various compounds, the relative ion bonding to exchange sites, and microbial activities. Depending on the predominant clay type, the pH may be used as a relative indicator of base saturation. Soil pH is also a critical factor in the availability of most essential elements for plants. Apart from nutrients, soil pH estimation is also critical in the assessment of soil health. Generally, plants prefer soils that are close to either side of neutrality. However, there are acid-loving crops and also crops that can withstand high soil alkalinity. Hence, good crop yields are possible in acid and alkali soils. With proper amendments, still higher yields can be obtained in acid and alkali soils (Motsara and Roy, 2008).Soil pH also has a considerable influence on the activity of soil micro-flora and on the availability of soil nutrients to crops. It is alsoimportant to estimate physicalproperties such as soil texture and soil structure(Motsara and Roy, 2008; Ganjali *et al.*,2013*)*.Lime is often added to composts for pathogen or acidity control therebyincreasing the calcium (Ca) content. The effect of compost on soil pH is likely to depend both on theinitial pH of the compost and the soil pH(Motsara and Roy, 2008;Barker, 1997).

Table 1: pH range and terms

Term	pH
Extremely acid	>4.5 – 5.0
Very strongly acid	4.5 – 5.0
Strongly acid	5.1 - 5.5
Moderately acid	5.6 – 6.0
Slightly acid	6.1 – 6.5
Neutral	6.6 – 7.3
Slightly alkaline	7.4 – 7.8
Moderately alkaline	7.9 – 8.4
Strongly alkaline	8.5 – 9.0
Very strongly alkaline	>9.1

(Motsara and Roy, 2008)

2.3.2.2 pH Interpretation(Motsara and Roy, 2008)

- pH<5.5: Soil is deficient in Ca and Mg and should be limed. Poor root growth due to low CEC and possible Al^{3+} toxicity. Phosphorus deficiency is likely.
- pHbetween 5.5 – 6.5: Soil is low in carbonate but should be monitored. Satisfactory for many crops.
- pHbetween 6.5 – 7.5: Ideal range for most crops. Soil CEC is near 100%.
- pHbetween 7.7 – 8.4: Free carbonate present in soil. Usually excellent infiltration and percolation of water related to high Ca saturation of clays.

- pH> 8.4: Typically, indicative of sodic soil. Poor soil physical conditions. Low infiltration and percolation. Possible root deterioration and organic matter dissolution.

2.3.2.3 Nitrogen (N)

Application of plant residues can be an essential source of nutrients in organic farming. It is well documented that different quantities of N, P, K and minor nutrients are removed from, and returned to, the soil depending on the crop species concerned (Hitchings, 2012;Vanlauwe *et al.*, 2010). Plant residues also contain variable amounts of lignin and polyphenols, which influence decomposition and mineralization rates (Vanlauwe*et al.*, 2010). Incorporation of N rich, low C:N ratio residues of fresh plant material, manures or composts leads to rapid mineralization and a large rise in soil mineral N. It is reported that at a C:N ratio of 15 or less mineralization occurs, above this N will be immobilized (Vanlauwe*et al.,* 2010). Thus, mineralization rates are usually greater from fresh material than composted material (Cooperband*et al.,* 2002). It has also been shown that in a given time period the proportion of total N mineralized is lower from composted residues, which generally have higher C:N ratios (Ekbladh, 1995). The challenge for organic farming is to manage the use of composts and manures to synchronize supply and demand for N.

2.3.2.4 Phosphorus (P)

P (0.1% - 0.4%) of dry plant extract plays a key role in energy transfer, so it is essential for the efficiency of photosynthesis (Pilar *et al.*, 2015). With continued application of composts and manures soil P levels will increase (Sharpley and Rekolainen, 1997). In soils already high in P, addition of composts and manures carries with it a risk of P runoff. Chelation of soluble aluminium and iron with organicmatter will restrict phosphorus fixation in soil (Sharpley and Rekolainen, 1997). Plants need P for the growth of roots and short tissues and the development of seeds and kernels of grain. P deficiency leads to stunted growth, slow emergence and growth, purple petioles, poor root development, less fruits and the plant will look spindly or stunted (Silas *et al.*, 2012). P in compost is not readily available for plant uptake. Similar to N it is incorporated in OM. However, a part of the mineralized P is quickly made unavailable by binding with other elements in the soil. About 20 to 40% of the P in compost is immediately available to plants and has been decomposed to ortho-phosphate. OM is not only a source of P, but can also reduce the capacity of acid soils and soils with a pH above 8 to fix P (Diacono andMontemurro, 2010; Silas*et al.*, 2012).

2.3.2.5 Potassium (K)

K (1% -4%) of the dry plant extract) plays a vital role in the synthesis of carbohydrates and proteins.Therefore, in the structure of the plant, potassium improves the hydrologic regime and increases its tolerance to drought, frost and salinity(Hitchings, 2012). In compost, K remains in water-soluble forms and thus does not need to be mineralized before becoming plant available. However, for the same reason, it is at risk of leaching during the composting process and thus compost is often a poor source of K(Barker, 1997). Composting of organic wastes does not appear to affect K availability but application may affect both soil K and plant K uptake (Silas *et al.*, 2012). K is required in enzyme activation, osmotic regulation, and regulation of stoma opening and production of high energy phosphate molecules. K deficiency leads to shortening of internodes, dwarfing, loss of green colour, marginal discoloration, premature death of older leaves, small size and quantity of fruits and white spots on leaves (Silas *et al*., 2012;Eghball, 2002).

2.3.2.6 Electric conductivity (EC)

EC is a measure of the salt concentration in the soil solution. Electrical conductivity has been shown to increase with increased manure/compost application rates (Eghball, 2002). It was observed that while municipal solid waste compost could induce salinity damage, the effects were likely to be much less than from sewage sludge applied at the same loading rate (Shiralipour*et al.*, 1992).

2.3.2.7 Cation exchange capacity (CEC)

CEC describes the ability of a soil to retain cations on soil colloids as a result of negative charges(Hitchings, 2012; Shiralipour*et al.*, 1992)). CEC is, thus, important for retaining nutrients and making them available to plants. Soil organic matter and clay minerals are the two most important constituents that influence soil CEC. Thus increasing soil organic matter through compost addition is likely to increase CEC (Jakobsen, 1996).

2.4 Biochar Properties

Biochar is a light weight, highly porous material with high carbon content, a portion of which has a stable chemical structure resistant to decay. Biochar is typically low in available nutrients, though contains some ash content, which adds some nutrients, and typically has an alkaline pH (Downie*et al.*, 2011). Though different biochar share these basic characteristics, all biochar have different specific characteristics depending on the properties of the feedstock and the pyrolysis parameters used for production (Chan &Xu, 2009).

Biochar improves soil quality through its effects on key soil processes. Many of the benefits of biochar derive from its highly porous structure and associated high surface area. Charges on the high surface area can increase CEC thereby increasing a soil's ability to retain and supply nutrients. Increased porosity can increase soil water holding capacity and the small pore spaces with positively charged surfaces can improve soil water retention and in turn reduce nutrient loss through leaching (Lehmann *et al.,* 2011;Verheijen*et al*., 2010). Charcoal in soils has also been linked to increased soil microbial populations which may increase beneficial soil processes mediated by soil organisms including nutrient availability (Lehmann *et al*., 2011). The majority of biochar adds little in terms of available nutrients to the soil and as such can be thought of as a soil conditioner, as opposed to a fertilizer (Sohi, *et al*, 2009).

Biochar is not intended to replace compost and in fact it is thought that the benefits of biochar will increase by adding biochar in combination with a source of nutrients and microbial life such as compost or a compost tea. This has been shown in previous field trials in which it was found that biochar added with a fertilizer or compost had greater results on crop yield than biochar used alone and in some cases (but not always) than the fertilizer used alone (Chan*et al.*, 2008;Asai*et al.*, 2009). Some trials have also seen improved crop growth with just biochar while some have found no benefit from adding biochar alone (Chan, *et al.*, 2008; Baronti, *et al.*, 2010).While there is clear evidence that biochar can have positive impacts on crop yield, there is significant variability and yield benefits are not observed in all cases.

2.5 Effects of compost on plant growth and development

2.5.1 Plant growth

The improvement of soil physical, chemical and biological properties by compost can improve plant growth. Compost amendments can increase shoot and root growth of tomatoes and root depth of Serpentine perennial grass (Curtis and Claassen, 2005). Compost increased fresh weight of parsley (Mylavarapu and Zinati, 2009), barley yield (Lillywhite*et al.*, 2009) cotton seed weight and the marketable weight of Chinese cabbage (Wang *et al.*, 2010). Compost application also stimulates seed emergence (Taban and Naeini, 2006). The positive effects of compost on plant growth are due to a number of reasons including nutrient supply, improved soil structure (Wang *et al*., 2010) and/or the increased soil water content.

2.5.2 Nutrient uptake

By supplying nutrients, particularly N, P and K, and organic matter, compost can improve plant nutrient uptake (Mylavarapu and Zinati, 2009;Asai*et al.,* 2009), but the effect depends on compost type as well as on application rate and method. Compost application increases plant growth and N mineralization rate, but high rates are required to meet the crop N needs (Evanylo*et al*., 2008) to ensure a continuous N supply to plants from compost similar to the supply of N from inorganic fertilizer (Mylavarapu and Zinati, 2009). Indeed, N recovery in sorghum biomass was significantly higher in the soil amended with compost in comparison to mineral-fertilized plots (Steiner *et al*., 2008). The N, P and K uptakes of plants increase with increasing rate of compost.

2.5.3 Water uptake and gas exchange

Water is crucial to plant physiological processes and plants require a large quantity of water for growth and development with 50 – 90% of fresh weight of plant being water (Lambers*et al.*, 2008). Water is a solvent for salts, molecules and mediates of chemical reactions. Water is the medium of transport for carbohydrates, phytohormones and nutrients, and organic molecules to shoots, stems and leaves (Ehlers and Goss, 2003). If there is an insufficient water supply, herbaceous plants and plant organs that lack supporting sclerenchyma will lose strength and wilt (Ehlers and Goss, 2003). When plants lose turgor, certain physiological functions will not be carried out and photosynthesis is lower.

Transpiration of water from leaves prevents overheating of the leaf surface which is critical in hot environments.

Compost application can increase transpiration and gas exchange of plant due to the increase in plant growth and leaf area index which increase potential water use by transpiration (Adamtey*et al.*, 2010). In turn, high water use for transpiration and photosynthesis stimulates dry matter production and leaf area index (Dagdelen*et al.*, 2006). Compost increases transpiration rate of tomatoes (Ozenc, 2008) and maize crops (Adamtey*et al.*, 2010), but compost application had no effect on net photosynthesis (Francesco and Baietto, 2007). On the other hand, it showed that compost increased both photosynthesis and stomatal conductance and these effects became stronger with increasing application rate. Compost application stimulates root growth and volume (Ozenc, 2008; Johnson *et al.*, 2009), which can increase the ability of plants to uptake more water (Curtis and Claassen, 2005; Adamtey*et al.*, 2010).

2.5.4 Nutrients requirement on maize plant growth and yield

Soil nutrient composition is critical in maize growth and yield improvement. Soil nutrient deficiencies have both direct and indirect effects on plant growth and development. It was reported that for each ton of maize grain obtained from a field, 15 kg of N, 3 kg of P and 4 kg of K is removed from the soil. By removing a ton of the whole maize plant 27 kg of N, 4.5 kg of P and 20 kg of K is removed from the soil (FSSA, 2000).

Nitrogen is required in high levels by maize for development and production. N is a most limiting nutrient elements in maize crop production. It plays a major role in photosynthesis and consequently influences crop yield capacity (Zhao, *et al.*, 2005). Adequate supply of N levels show dark green color of leaves whilst deficiencies result in leaf chlorosis (Tajul*et al.*, 2013). Deficiencies may also result in slow stunted growth and weak plants. Maize grain quality and quantity are improved with adequate nitrogen levels in the soil.

Phosphorus is an essential element in the production of maize, but it is not required in as high amounts as N (Dlamini, 2016). The deficiency symptom of phosphorus in maize is characterized by stunted growth and with plants sometimes being dark green in colour. Older leaves may also show purple pigmentation (O'Keefe and Schipp, 2009). Its deficiency during kernel formation in maize may result in poor kernel set; hence affecting grain yield (O'Keefe and Schipp, 2009).Phosphorus availability to plants in the soil may be influenced by soil parent rock material low in P, soil compaction, low soil pH, soil temperature, and soil moisture content.

Maize requires K levels between 80 and 160 mg kg^{-1} in the soil to obtain optimum yield (FSSA, 2000). Potassium is the second essential nutrient required by maize, after N. A major deficiency symptom of potassium in maize is the scorching of leaf margins. It may result in weak and lodged plants and poor kernel set; hence poor quality and quantity of grain (Ramson, 2013).

2.5.5 Crop N uptake in relation to soil N

Nitrogen acquisition of crop plants is usually dominantly by the uptake of NO_3^- and NH_4^+, although soil organic nitrogen can be taken up by plants and may represent a significant proportion of total N absorption under particular ecological situations like acidic soils and low temperature environments (Gastal and Lemaire, 2002). The mineral nitrogen content is generally greater in upper compared with lower soil layers, probably due to more favorable conditions for N mineralization in the upper part of the soil (higher content in organic matter; higher O_2 diffusion) (Gabrielle *et al.,* 1998;Gastal and Lemaire, 2002). This appears contrary to a dependence of crop N uptake on rooting depth. However, rooting depth determines the ability of a crop to intercept nitrate during periods of leaching and hence may be important from an environmental perspective (Gabrielle *et al.*, 1998). In this respect, not only the rooting depth of mature crops but also the rate at which roots of seedlings develop at depth will be important, particularly for crops which have an early phase of development during winter, the period where water drainage occurs most frequently (Robinson, 1994; Zhang and Forde, 2000). Rooting depth varies greatly between species and therefore each species requires individual evaluation. Several studies have indicated that soil N availability, although strongly altering shoot growth, does not significantly affect the dynamics of root growth at depth (Gabrielle *et al.*, 1998). The relatively small effect of N supply observed on rooting depth, in comparison to the large effect on shoot growth, probably relies on the decrease in root: shoot ratio observed with increasing N supply (Gastal and Lemaire, 2002). Both root density and architecture also vary to a large extent between species (Fitter, 1991). In several species it has been observed that local NO_3^- application induces root proliferation due to an increased growth of laterals (Robinson, 1994; Zhang and Forde, 2000). However, root growth responses to a localized N supply differ between species. In addition, a large range of root morphological plasticity in response to non-uniform distribution in soil N exists (Robinson, 1994). As recently suggested, the impact of root proliferation on N uptake may be limited and more critical for plant-to-plant competition in N uptake, than for N uptake of a whole plant population such as a crop (Hodge *et al.*, 1999).

It has been reported, in hydroponic studies, that uptake of NO_3^-or NH_4^+) depends on the NO_3^- or NH_4^+) concentration in the nutrient solution in a hyperbolic relationship often with multiphasic kinetics implying a complex regulation of uptake (Tischner, 2000). It has been established that soil NO_3^- concentration regulates crop N uptake, not only under situations of low but also under situations of high soil NO_3^- concentration, when crop N is above its critical N concentration and where excess N accumulation in plants occurs(Devienne-Barret*et al.*, 2000). The regulation of whole plant and crop N uptake in heterogeneous soil remains poorly understood (Tischner, 2000; Devienne-Barret*et al.*, 2000).

The amount of N taken up by the crop has a major impact on overall crop growth rate. The dependence of crop growth on crop N relies on several processes which include leaf photosynthesis–N relationships, the distribution of N between leaves, leaf expansion and positioning and subsequent impacts on light interception (Gastal and Limaire, 2002).

2.6 Fertilization

Compost contains fertilizing elements for plants, although in an organic form and in a smaller amount than synthetic mineral fertilizers (Pilar *et al.*, 2015). One of the biggest advantages of using compost as input of organic matter is that it contains available nutrients of slow release, beneficial for plant nutrition. It is recommended to perform soil test to know soil chemical composition before applying compost or mineral fertilizer(Pilar *et al.*, 2015). The nutrients needed for plant growth come from air, water and soil, but soil solution is the means of transport of nutrients. They are divided into macro- and micro-nutrients, depending on the amounts that the plant needs. Primary macro-nutrients are nitrogen, phosphorus and potassium, and secondary macro-nutrients are magnesium, sulphur and calcium. Micro-nutrients are required in very small quantity but, in general, are important for plant and animal metabolism. These include iron, zinc, manganese, boron, copper, molybdenum and chlorine. Nitrogen, N (1% - 4%) of the dry matter of the plant) is the growth engine of the plant because it is involved in all major processes of plant development. A good nitrogen supply is also important for the absorption of other nutrients. Each crop requires a specific quantity of nutrients that depends on the expected crop yield. To calculate the actual requirement of fertilizers, other factors such as soil nutrient reserves and immobilization or loss of nutrients when applied either by fixation or leaching should be taken into account(Bilen, 2008).

A mineral fertilizer is such industrialized product containing at least 5% of one or more of the primary nutrients (N, P, and K). These nutrients are generally expressed in percentages of N, P_2O_5, and KO. These fertilizers can be simple fertilizers (one primary nutrient) or compound (multi-nutrients) (Pilar *et al.*,2015). The Table 2 below showed the most commonly fertilizers used and the properties.

Table2: Fertilizer most commonly used

Fertilizer source	Molecular formular	N	P_2O_5	K_2O
Urea	$CO(NH_2)_2$	46	-	-
Ammonium nitrate	$NH_4(NO_3)$	34	-	-
Ammonium Sulphate	$(NH_4)_2SO_4$	21	-	-
Monoammonium phosphate	$NH_4H_2PO_4$	12	50	-
Simple Superphosphate	$Ca(H_2PO_4)_2$	-	20	-
Potassium Chloride	KCl	-	-	60
Potassium Sulphate	K_2SO_4	-	-	52
Compost	-	0.6	0.7	0.6

Source: (Pilar *et al.*, 2015)

To decide on the application of compost as organic fertilizer as well as integral nutrition with mineral fertilizers, the following parameters should be taken into account: Crop fertilization requirement (soil and leaves analysis), access and availability of both fertilizers locally, cost of both fertilizers, and soil requirements of organic matter(Pilar *et al.*, 2015). Table 3 below showed average nutrient content in compost.

Table3: Average nutrient content in compost

Nutrient	Percentage in compost
Nitrogen	0.3% – 1.5% (3g to 15g per kg of compost)
Phosphorus	0.1% – 1.0% (1g to 10g per kg of compost)
Potassium	0.3% – 1.0% (3g to 10g per kg of compost)

Source: (Pilar*et al*., 2015).

2.7 Compost maturity and stability

Compost is sufficiently stabilized when the rate of oxygen consumption is reduced to the point that anaerobic or malodorous conditions are not created such that they interfere with the storage, marketing and use of the end product (Haug, 1993). A stabilized compost should not have problems with vermin attraction, pathogen re-growth or other problems resulting from its incomplete decomposition. As composting is an aerobic microbial process methods based on microbial activities are considered by researchers and regulators to be the most logical to use for the assessment of compost stability (Bernal *et al*, 1998).

Compost stability depends on several factors such C:N ratio, pH, organic matter, moisture and porosity of the biomass and the duration(Anwar *et al.,* 2015). Temperature is another parameter to evaluate evolution of the composting process, since it determines the biological reactions rate(Guo *et al.,* 2012). C:N proportion is a most widely used parameter in composting. Generally, composting could be carried out under a wide range of initial C:N ratios, namely, 11 to 105, depending on the starting materials (Ghosh*et al*, 2012). A decrease in the C:Nratio implies an increase in the degree of humification of the organic matter(Bilen, 2008; Anwar *et al.,* 2015). The aeration rate (AR) is considered to be the most important factor influencing successful composting. Insufficient aeration can lead to anaerobic conditions due to the lack of oxygen, while excessive aeration can increase costs and slow down the composting process via heat, water and ammonia losses. The optimal AR depends on the composition of the raw materials and ventilation methods (Guo *et al.,* 2012).

2.7.1 Maturity and stability assessment of compost

Compost prepared from different organic waste materials differed in their quality and stability; and quality is closely related to stability and maturity. Hence it is important to define maturity and stability. Compost maturity is the degree or level of completeness of composting. It is described by several physical, chemical and biological properties and therefore maturity is best assessed by measuring two or more parameters of the compost. Compost stability refers to specific stage or decomposition or state of organic matter during composting, which is related to the type of organic compound remaining and the resultant biological activity in the material.

Several parameters have been proposed for evaluating compost maturity and stability (Bernal *et al.,* 2009; Raj and Antil 2011; Antil*et al.,* 2012). However, there is no single method that can be universally applied to all types of composts due to variation of materials and composting technology (Itavaara*et al.,* 2002; Benito *et al.,* 2003; Chang and Chen, 2010).

In addition to above parameters, the physical characteristics such as colour, odour, particle size, appearance of larvae of secondary consumers also show the decomposition stage, but give little information with regard to degree of maturation. The maturity of compost, which may defined as the degree of compost stability in physical, chemical and biological properties is an important factor affecting successful application in agriculture and its impact on environment.

2.7.2 Physical parameters

Physical parameters are frequently used but they give only general information regarding maturity of compost (Raj and Antil, 2012).Some notable physical parameters are colour, odour, temperature and weight loss.

2.7.3 Colour and odour

During composting of organic wastes, a gradual darkening or melanisation of the material takes place. The final product, after a sufficiently long period of maturation, is dark brown or almost black colour (Antil 2012). Sugahara*et al* (1979) proposed a simple technique to determine the maturity of compost by measuring the degree of darkness of composting material. It is also possible to monitor it visually the gradual process of compost darkening. In general, unpleasant odour emission takes place during first thermophilic phase and then starts decreasing, with the maturity of the compost.

2.7.4 Temperature

Temperature evolution is an indication of microbial activity during the composting process. The temperature in the compost heap increased to thermophilic range (60 – 70^{o}C) during the first few days and then decreased gradually to a constant temperature and finally reached to ambient level (Raj and Antil 2011, 2012b). Stickelberger (1975) stated that compost is matured enough when its temperature remains more or less constant and does not vary with the turning over the material.

2.7.5 Weight loss or organic matter loss

The weight loss determination is the simplest procedure to measure the mineralization rate of OM during composting. The cumulative loss of organic matter increased with composting time in all types of composts and also measured in the form of weight loss. The weight loss/OM loss was found highly correlated with C:N ratio and other maturing parameters (Chefetz*et al* 1996; Raj and Antil 2012). However, thorough examination of maturity parameters involving a long term study of a single compost pile may find some correlation between them and curing time of compost (Wu *et al.,* 2000).

2.7.6 Chemical parameters

Chemical methods are widely used to assess the compost maturity. These parameters are more reliable than the physical parameters. Some chemical parameters are pH, EC, and C:N ratio.

2.7.6.1 pH

The pH is a good indication showing the development in different stages of composting. The pH dropped slightly at the beginning of the compost process due to production of organic acids. Soon after, on utilization of these acids as substrates by other aerobic microbes, the pH increased, during the cooling and maturation stages, following lowering in pH and reached a value close to neutral (Satisha and Devarajan, 2007; Ko*et al.*,2008). This trend of pH could be used to monitor the stabilization and maturation of compost (Wu *et al* 2000; Raj and Antil 2012).

2.7.6.2 EC

The EC is a measure of dissolved salts in the compost. This measure is significant because it reflects the salinity of the compost, and overly saline compost is likely harmful to plant. The sum of soluble salts in the water extracts is increased with the maturation of compost because of release of organic acids and soluble salts during organic matter decomposition indicating the stability of compost (Avnimelech*et al.,* 1996; Wu *et al.,* 2000).

2.7.6.3 Carbon - nitrogen ratio (C:N)

C:N is important in determining in general terms the rate of decomposition of organic materials. High C:N ratios make the process as there is an excess of degradable substrates for the microorganisms. But with a low C:N ratio there is an excess of N per degradable C and inorganic N is produced in excess and can be lost by ammonia volatilization or by leaching from the composting mass. Then, low C:N ratios can be corrected by adding a bulking agent to provide degradable organic C. This is the criteria traditionally used to determine maturity of compost. The relevance of C:N ratio relies on the fact that a decrease in ratio implies in the degree of humification of organic matter. As the decomposition progressed due to losses of carbon mainly as carbon dioxide, the carbon content of the compostable material decreased with time and N content per unit material increased which resulted in the decrease of C:N ratio. It has beenreported that a C:N ratio below 20 was assumed to be indicative of maturity of compost a ratio 15 or less is preferable (Bernal *et al.*,2009). On the other handSellami*et al*(2008) and Goyal*et al*(2005) both reported that C:N ratio alone is not sufficient criteria to determine the compost maturity.

2.8 The experimental test crop (Maize)

2.8.1 Background information on maize

Maize (*Zea mays L*) is a cereal crop adapted to a wide range of environmental conditions and is cultivated in all agro-ecologies of West and Central Africa. It is used for many different purposes including food for humans, feed for livestock, and raw material for agro-allied industries(Badu-Apraku *et al.,* 2012).Good management practices are essential for the production of a high yield in maize. The management practices include seed dressing, thinning, the filling of vacancies in plant stands (supplying) and cultivation, control of weeds, diseases, insects, and vertebrate pests, fertilizer application, and timely harvesting(Badu-Apraku *et al.,* 2012). Maize requires a large amount of readily available plant nutrients and a soil pH between 5.5 and 8. Fertilizers promote the vigorous growth and high productivity of maize. N, P, K, and some micro-elements are required by maize plants and must be supplied by the soil.On poor soils, vegetative growth may use most of the available nutrients leaving little for grain production. When the crop is growing, N fertilizers should be applied, because the roots will quickly absorb it and prevents losses from leaching or denitrification. All N should be applied before tasseling (Ogbonna*et al.*,2012). Generally, vegetative parameters including, maize stem length, girth, number of leaves and leaf length, were reported to have significantly influenced by the use of compost at different concentrations (Ogbonna*et al.*,2012).

2.8.2 Maize growth stages

This identification system divides plant development into vegetative (V) and reproductive (R) stages. The (V) stages are designated numerically as V1, V2, V3, etc. through V(n) where (n) represents the number of leaves with visible collars and demonstrated in figure 1(Badu-Apraku *et al.*, 2012). The first and last (V) stages are designated as VE (emergence) and VT (tasseling). The six reproductive stages are simply designated numerically. In the Vegetative and Reproductive Stages, each leaf stage is defined according to the uppermost leaf whose leaf collar is visible. Loss of the lower leaves will begin about V6 due to increased stalk size and nodal root growth. To determine the proper leaf stage after lower leaf loss, split the stalk lengthwise and inspect for internode elongation. The first node above the first elongated internode is generally the fifth leaf node. This fifth leaf node can be used as a reference point for counting the top leaf collar(Badu-

Apraku *et al.*,2012). The figure 1 and Table 5 showed the various stages of maize plant growth as well as the description of vegetative and reproductive stages of maize plant respectively.

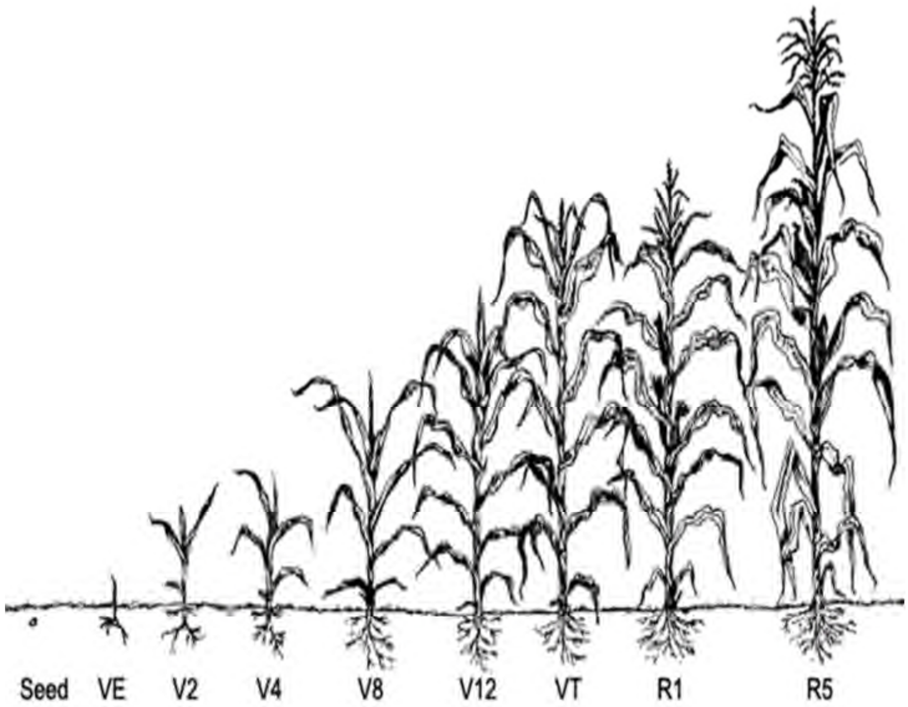

Figure 1: Growth stages of maize plant (Badu-Apraku *et al.,* 2012)

2.8.2 Vegetative growth of maize

Maize seed absorb water from the soil and begin to grow soon after planting. Emergence is said to occur when the coleoptile (spike) pushes through the soil surface (Ransom, 2013). Maize plants can emerge within five days in ideal heat and moisture conditions. Planting to emergence under early season cool conditions may require roughly two weeks. Below average spring temperatures, maize seed may be in the ground for three weeks or more before the seedlings emerge (PANNAR Handbook, 2013). The growing point grows between 2.5 to 3 centimeters below the surface. The seminal root system grows from the seed (Figure 1). The seminal roots provide much of the plant nutrients at this stage, but growth slows after emergence as nodal roots begin to grow (OGTR, 2008). A balanced soil nutrient status amongst other factors promotes optimum seed germination and emergence at this stage(O'Keefe and Schipp, 2009).

The young plant develops to the point that the collars start showing on the first leaf (Figure 1). This leaf is usually more rounded at the tip than succeeding leaves (OGTR, 2008). Each vegetative stage is determined by counting the visible collars in the sequence; V1, V2, to VN until the tassel emerges (VT) and maximum height is attained. When counting leaf number at these stages, it is important to consider that leaves may have been lost from the bottom of the plant (PANNAR Handbook, 2013). At the V1 stage leaves are initiated from a growing point below the soil surface as cell elongation has not yet begun. The initial seminal root system continues to grow and expand with branches and hair roots. The beginning of the nodal root system may also be visible as bumps at either one or two nodes at the lower end of the coleoptile and above the mesocotyl (PANNAR Handbook, 2013).

At V3 stage, the stalk (stem) has not elongated much. Root hairs are growing from the nodal roots as seminal roots cease growing. All leaves and ear shoots the plant will ever produce form inside the stalk from V3 to about V5 (Lee, 2012). A tiny tassel forms at the tip of the growing point. Above-ground plant height is typically about 20 cm at this stage(O’Keefe and Schipp, 2009). The growing point and tassel rise higher above the soil surface at about the V6 stage. The stalk begins to elongate. The nodal root system grows from the three to four lowest stalk nodes (OGTR, 2008). Some ear shoots or tillers are visible. Tiller (or sucker) development depends on the specific hybrid, plant density, soil fertility and other conditions (O’Keefe and Schipp, 2009; Ramson, 2013).

2.8.3 Maize reproductive development

A cross-sectional dissection at V9 plant growth stage shows ear shoots (Lee, 2012). These develop from every above-ground node except the last six to eight nodes below the tassel. Lower ear shoots grow fast at first, but only the upper one or two develop to a harvestable ear (O’Keefe and Schipp, 2009). The number of kernel rows is also determined by the growing conditions at V9 (PANNAR Handbook, 2013). The tassel begins to develop rapidly. Stalks lengthen as the internodes grow (O’Keefe and Schipp, 2009). At V10, the time between new leaf stages shortens to about every two to three days. The total number of leaves will vary from 12 to over 20; depending on hybrid maturity and genetic make-up (Ramson, 2013).

The potential number of kernels per row is determined between the V12 and V15 stages. Between these stages, the top ear shoot is still smaller than the lower ear shoots, but many of the upper ears are close to the same size. This is the commencement of the most crucial period in determining grain yield. Upper ear shoot development overshadows lower ear shoot development (PANNAR

Handbook, 2013). Every one to two days, a new leaf stage occurs. Silks begin to grow from the upper ears (Lee, 2012).

Atthe V17 growth stage, the tips of the upper ear shoots may be visible atop the leaf sheaths. The tip of the tassel may also be visible. Just before tasseling, silks from the basal ear ovules elongate first (O'Keefe and Schipp, 2009). Silks from the ear tip ovules follow. Aerial nodal roots grow from the nodes above the soil surface to help support the plant and take in water and nutrients during the reproductive stages (Nazfiger, 2010).The VT stage is when the last branch of the tassel is completely visible (Fig 2). VT may begin about two to three days before silk emergence; the plant is nearly at its full height (Ramson, 2013). Pollen shed begins, lasting about one week on an individual plant basis and one to two weeks on a field basis (Laekemariam&Gidago, 2012). The interval between VT and R1 can fluctuate considerably depending on the hybrid and the environment. Drought stress lengthens this interval (Nazfiger, 2010).

Table 4: Description of vegetative and reproductive stages of maize plant

Vegetative Stages		Reproductive Stages	
Stage	Description	**Stage**	Description
VE	Emergence	**R1**	Silking - silks visible outside the husks
V1	One leaf with collar visible	**R2**	Blister - kernels are white and resemble a blister in shape
V2	Two leaves with collars visible	**R3**	Milk - kernels are yellow on the outside with a milky inner fluid
V(n)	(n) leaves with collars visible	**R4**	Dough - milky inner fluid thickens to a pasty consistency
VT	Last branch of tassel is completely visible	**R5**	Dent - nearly all kernels are denting
		R6	Physiological maturity - the black abscission layer has formed

Source: (Ramson, 2013)

2.8.4 Factors affecting the growth of maize

Maize can be grown in tropical, sub-tropical and temperate climates and highest production occurs between 21 and 27 ^{O}C with an average annual precipitation of 250 to 5000 mm. Soil water availability is often the main factor limiting rain fed maize production. In these water-limited systems, efficient capture and retention of precipitation is essential to maximize crop growth (Roygard*et al.*, 2002). Many studies have shown maize grain yields to beespecially sensitive to moisture stress at a period beginning approximately at tasseling and continuing through grain filling (Ramson, 2013). Drought which coincides with this growth period can cause serious yield instability atthe farm level, as it allows no opportunities for farmers to replant or otherwise compensate for loss of yield.

The maize crop can tolerate a wide range of temperatures (from 5 to 45 °C), but very low or very high temperatures can have a negative effect on yield. Nielsen (2007) found that maximum temperatures greater than 32 ^{o}C around tasseling and pollination speeded up the differentiation process of the productive parts and resulted in higher rates of kernel abortion and yield reduction (Ramson, 2013).

Soil characteristics have an important bearing on the productivity of the maize crop. Below pH 5, toxicity of Al, Mn and Fe may be encountered, though maize is relatively tolerant. At very low pH, soils are likely to be deficient in P due to tying up with the active Al component. In addition, production of NO^{3-} from $NH4^{+}$ is greatly retarded dueto inactivity of the *nitrobacter* organism (Hill, 2007). At high pH levels, nutritional problems are often encountered with the elements P, Zn and Fe. For example, in calcareous soils with pH 7.5 to 8.4, P is deficient because virtually all phosphate ions are converted to low solubility *tricalcium* phosphate, forming carbonated apatite. They further noted that Zn and Fe might also have low solubility at high pH and be deficient to the crop. Hill (2007) noted that N, P and K are taken up slowly during the seedling growth, then rapidly during the active vegetative growth and grain filling stages. N and P uptake continues until near maturity but K absorption is largely completed by silking time. The major portionof the N and P taken into the early shoot, stalk, leaves and tassel are translocated into grain, much less so with K. Two-thirds to three-fourths or more of K remains in the stover. Thus N and P tend to be depleted rapidly from soil with cash grain farming, but K is not (Roygard*et al*., 2002).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

This chapter describes the study area, compost/treatment properties used for the experiment. A section also looks at experimental design used, treatment application and planting, sampling procedure and analysis. Another section also looks at data collection methods on vegetative and reproductive (yield) data, soil analysis and nutrient uptake. A section also deals with the procedure on compost maturity and stability experiment and finally explanation on the statistical tool used in data analysis.

3.2 Study area

The experiment was conducted at an open space urban garden, south of Tamale Sports Stadium between June to September 2015 cropping season.The Area has a unimodal rainfall distribution pattern which gives single growing season with mean annual rainfall of 1,100mm. The experiment was established on a sandy soil with low fertility Arenosolaccording to World Reference Based – Food and Agriculture Organization classification (WRB-FAO). Most farmers around the study area grow vegetables except few who cultivate maize and harvest for fresh consumption. The map of the study area is below in Figure 2 and area marked blue was the experimental site. Analysis of The soil, compost and plant samples analysis was carried outat the University for Development Studies and Soil Research Institute of CSIR, Kwadaso, Kumasi.

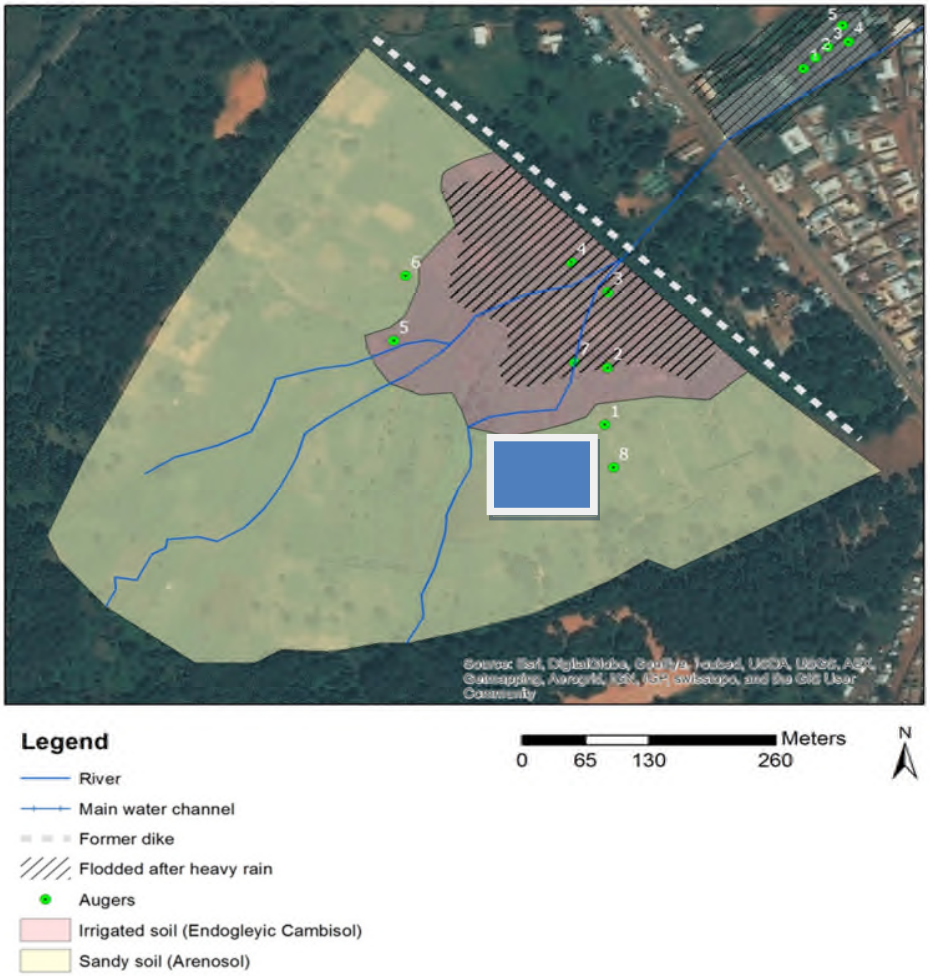

Figure 2: Map of experimental study area

3.3 Composting process and amendment properties

Six compost treatments were made with rice straw (60%vol, **plate 1**), poultry manure (15%vol,**plate 2**) and either amended with uncarbonized corn cobs (25% vol, **Plate 3**), uncarbonized sawdust (25% vol, **Plate 4**) and uncarbonized rice husk (25% vol, **Plate 5**) or their carbonized corn cobs (25% vol, **plate 6**), carbonized wood (25% vol, **plate 7**) and carbonized rice husk (25% vol, **plate**

8).In addition two other treatments (described as multi-grow) developed from co-composting *Danielliaoliveri* sawdust or jasmine 85 variety rice husk with poultry manure (in a ratio of 2 parts of feedstock to 1 part poultry manure) were set as additional treatments. The last two amendments used in the experiments is the normal or conventional type of compost. The plates 1 to 8 showed treatment combination of basic mixture with carbonized and uncarbonized feedstock during composting.

Plate 1: Basic mixture of (60 vol-%) Rice straw

Plate 2: Basic mixture of (vol-15%) Poultry manure

Plate 3: Uncarbonized maize cobs (25% vol)

Plate 4: Uncarbonized sawdust (25% vol)

Plate 5: Uncarbonized ice husks (25 % vol)

Plate 6: Carbonized maize cobs (25 % vol)

Plate 8: Carbonized sawdust (25 % vol)

Plate 7: Carbonized rice husks biochar (25 % vol**)**

The co-composting was done for 34 days in randomly allocated 1m³ compost bins (three replicates each) as showed in plate 9. Initial filing of feedstock was done in layers of 1.5 buckets of poultry manure, 6 buckets of rice straw and 2.5 buckets of the treatment (carbonized or uncarbonized feedstock) and three cans of water.

Plate 9: Nyankpala campus compost production site

Table 5: Amendmentdefinitions

S/N	Composting feedstock composition	ID Code
1	Uncarbonized rice husk compost	R_0
2	Uncarbonized maize cobs compost	M_0
3	Uncarbonized sawdust compost	S_0
4	Carbonized rice husk compost	R_1
5	Carbonized maize cobs compost	M_1
6	Carbonized sawdust compost	S_1
7	Sawdust multi-grow compost	G_1
8	Rice husk multi-grow compost	G_2
9	Normal Agriculture Practice (farmer rate of NPK)	NAP
10	Control (no amendment)	CO

3.4 Experimental design

The experiment consisted of 10 treatments, laid out in Randomized Complete Block Design (RCBD) with four replications.Plots were numbered in a serpentine order of one to forty (1-40) as shown in Table 3.1. Blocks and plots were pegged and separated from each other by 0.8 m and 0.5 m respectively. Three ridges of 110cm distance were prepared to fit a suitable plot size of 3.5m x 3.3m (11.55m^2).

Table 6: Experimental field layout

BLOCK 1		BLOCK 2		BLOCK 3		BLOCK 4	
R_0	CO	S_0	R_1	S_0	R_1	CO	R_0
S_1	G_1	R_0	S_1	CO	S_1	M_1	G_1
S_0	R_1	M_1	M_0	M_1	M_0	G_2	R_1
M_1	NAP	CO	G_1	R_0	NAP	NAP	S_0
G_2	M_0	G_2	NAP	G_1	G_2	S_1	M_0

The NAP treatment follows the rate of N input in accordance with the procedure being practiced by farmers around the experimental area. The rate of application of other amendments was done to equate with the Farmer N input as in NAP.All other treatments followed the NAP plot management regarding tillage system, weeding, and type, quantity and application dates of planting seeds and applying pesticides.

The only difference between NAP and the other treatments was that composts or biochar were applied instead of NPK and Ammonia fertilizers. The treatments were applied on the soil surface and incorporated into the soil prior to ridge preparation. Maize variety, Obaatanpa was used as the test crop. The planting was done on 3rd July 2015 at 40 cm within rows and 80 cm between rows with 2 seeds per hole. The compost application rate was adjusted according to the NAP fertilizer N application. It was around 2 kg/m^2.Treatment application rate was NPK (15:15:15) 450 g per plot size of 11.55m^2/ha and AmmoniaSulphate 450g per plot and Composts 1100 g per plot of the same plot size.NPK 15:15:15 was applied on 20th July 2015 a few days after germination and then Ammonia sulphate at flowering stage. Additional information about NAP was gathered by interviewing farmersworking around the siteand in adjacent fields No diseases or harmful insects were observed during the season, therefore no pesticides or insecticides were applied. Harvestingwas done by hand on 7th October, 2015.

The experimental field was made up of two fields belonging to two farmers with field size of 1702m^2 and 352m^{2}for Farmer 1 and Farmer 2 respectively.An N-Input field calculation was done in respect of the individual fields as shown in Table 8 below. Plates 10 and 11 showed field layout with ridges and germinated plants.

Table 7: Field input calculations

Plot size	NPK 15:15:15 per plot	Ammonium sulfate per plot	Compost per plot
11.55 m²	450 g	450 g	1100 g
$11.55m^2$	5^{-5}g/ha	5^{-5}g/ha	11^{-5}g/ha

Where $\frac{R \times A \times 100}{10.000 \times C}$

R = rate of fertilizer to be applied (kg / ha).

A = area of plot (m2).

C = concentration of element in fertilizer (%).

10,000 = area per ha (m^2)

Plate 10: Field layout with prepared ridges for sowing

Plate 11: Germinated plants on experimental field

3.5 Sampling and preparation

3.5.1 Soils

In order to characterize the soil of the experimental field, samples were taken across the field to a depth of 20 cm and bulked for laboratory analysis. Two volumetric soil sample replicates were taken before and after compost application on each plot. Soils samples were taken at the end of the rainy season (after harvest) in two replicates per plot.

In the laboratory, the soil samples were air-dried, crushed using a wooden mortar and pestle and then sieved through a 2 mm mesh. The sieved samples were stored in polythene bags forchemical and physical analyses at the Faculty of Agriculture Laboratory of the University for Development Studies in Nyankpala, Soil Research Institute atKwadaso-Kumasi. The soil samples were analyzed for total C, total N, available P, and pH. Plate 11 showed the processes in collecting soil samples in the field.

Plate 12: Collection of soil samples in the experimental field

3.5.2 Bulk density

Samples for bulk density were taken with Kopecky rings at harvest. Before inserting the metal ring, 2 cm of the surface soil was removed. The ring was inserted, using an auger and excessive soil around the ring was removed with a knife. After weighing the sampled soil, the samples were dried at 105°C for 2 days and the dry weight was measured. Bulk density was estimated using the following formula:

$$\text{Bulkdensity}\ (\text{gcm}-3) = \frac{(\text{wt1}-\text{wt2})\text{g}}{\text{v}(\text{cm3})}$$

Whereby:

wt1 = initial weight (g) of soil after sampling

wt2 = final weight (g) of soil after drying in an oven at 105°C for 2 days and V = volume (cm^3) of metal cylinder used for sampling.

3.5.3 Soil pH

Soil pH was measured in a 1:1 soil-water ratio using a glass electrode pH meter(Motsara and Roy, 2008). Twenty five(25 g) of soil were weighed into a 50 ml polythene beaker and 25 ml of distilled water was added to the soil. The soil-water solution was stirred thoroughly and allowed to stand for 30 minutes. After calibrating the pH meter with buffers of pH 4.01 and 7.00, the pH was read by immersing the electrode into the upper part of the soil solution and the pH value recorded.

3.5.4 Organic Carbon (Walkey and Black Method)

About 98.07g of potassium dichromate (1 N $K_2Cr_20_7$) (oven-dried for 2 hours at 120 C) was dissolved in a 2 litre volumetric flask containing 1500 ml of water. When the dissolution was completed, the solution was transferred into a dark glass bottle with a Concentrated H_2SO_4 (98%) 0.025 N ferroin. A weighed of 1.485g of monohydrate orthophenantroline ($C_{12}H_8N_2$. x H_2O) and 0.695g of ferrous sulphate ($FeSO_4$.$7H_2O$) was dissolved with deionized water in a 100ml volumetric flask. The solution was then stored in a dark glass bottle. 0.5 N MOHR'S SALT was dissolve in 196.1g of ferrous ammonium sulphate [$FeSO_4(NH_4)_2(SO4)_2.6H_2O$)] in a 1000 ml volumetric flask containing 600 ml of water with an addition of 20 ml of concentrated sulphuric acid. When the dissolution was completed, the make-up volume was stored in the fridge with a dark bottle(Motsara and Roy, 2008).

A weighed of 1g of soil was placed in a 250 ml in Erlenmeyer flask. Then, under the hood, 5 ml of potassium dichromate was added into a 10 ml of concentrated sulphuric acid. The solution was left to rest for 3 hours. Then addition of 75-100 ml of deionized water and 2-3 drops of ferroin was titrated with Mohr's salt. At the same time a preparation of a blank with 5 ml of dichromate and 10 ml of sulphuric acid was made.

The result was calculated and expressed as Organic carbon(O.C) or as organic matter (O.M).

$$\%O.C = \frac{(b - a) \times N \times f \times 0.39)}{W}$$

Where, b = ml of Mohr's salt used for the blank

a = ml of Mohr's salt used for the sample

N = normality of Mohr's salt

F = normality correction factor

W = weight of the sample

Also, the percentage O.M is obtained from the formula below.

$$O.M.\ \% = O.C. \times 1.724$$

3.5.5 Total Nitrogen

The distillation method was used to analyze the Total Nitrogen content. A 25 ml of 0.1N H_2SO_4 was put in a 500 ml Erlenmeyer flask and added with about 200mls of distilled water and two / three drops of mixed indicator. The Erlenmeyer flask was put on the distiller and checked whether the end of the condensation pipe was covered by the acid. The distillation was done using the following program: 5ml water, 60 ml of 40% NaOH, Pause 0 minutes, Steam flow rate 100%, Distillation time, 5 minutes, Suction residues NO. After the distillation, it was titrated in the Erlenmeyer flask with 0.1 NaOH until the final color was changed from red to green(M.R. Motsara, 2008).

Furthermore, Motsara provided the formula for the calculation of percentage nitrogen in a soil sample as shown below.

$$\% \text{ N} = \frac{((\mathbf{25} - \mathbf{a})\ \mathbf{x14})}{\mathbf{W}(\mathbf{gr})} \text{ x } 100$$

Where:

25 = ml of 0.1 N H_2SO_4 used in the beaker

a = ml of 0.1 NaOH used in the titration

W = weight of the soil in grams

14 = molecular weight of nitrogen

3.5.6 Available Phosphorus (Bray and Kurtz's method no.1)

Soil samples were weighed 5g and placed in a 100 ml plastic bottle. 35 ml of extracted solution which was added and agitated for 5 minutes in the horizontal shaker and then filtered or centrifuged for an adequate amount of extract. 1 ml of extract was collected with a pipette and placed it in a test tube with an addition of 9 ml of working solution and then agitated and waited for 1 hour. The absorbance was measured on the spectrophotometer at 720 nm (lower sensitivity) using the blank as reference(M.R. Motsara, 2008). The concentration of phosphorus in the extract wasdetermined using the calibration curve and then related to the phosphorus in the soil using the following formula:

$$P_{\text{ppm/soil}} = P_{\text{mg}}/1 \text{ x } \left(\frac{35}{W(g)}\right) \text{ x f}$$

Where: W (g) = weight of the sample in grams

f = dilution factor

If phosphorus is expressed as P_20_5 the calculation is as follows:

$$P_{\text{ppm/soil}} = P \text{ mg/1 x } \frac{40}{W(gr)} \text{x f x } 2.2914$$

3.6 Data collection

Data was grouped into; growth parameters and above ground biomass, soil data, and nutrient uptake. Growth or vegetative parameters taken included; plant height, stem girth, number of internode, internode length, plant population per plot. Data on above ground biomass included total fresh weight of biomass and edible, dry weight of sample chaffed and edible. Data on the compost and soil included: pH, available P (Bray), total C, and total N. Data on nutrient uptake included; Total P, total C, and total N.

3.6.1 Sampling at Physiological Maturity

Fresh and dry aboveground maize (*Zea mays L*) biomass was weighted at physiological maturity and analyzed for their nutrient content. Fresh and dry cob weights were measured. Fresh weights were determined in the field with an analog balance. Plant number per plot was counted. Two plants per plot were randomly sampled and cut into small pieces and air driedin a secured sunny place. These air dried samples were put in the oven for 24 hours at 70°C. Then oven dry weight was measured with an accurate digital balance (minimum 2 digits). Maize stover and grains were milled and sieved through a 20 mesh for plant nutrient analysis.The grounded fine powder substances were ready for analysis for which 0.1g of each plant sample was analyzed in the laboratory. Total nitrogen (N), phosphorus (P) and potassium (K) were determined according to the method described by (Motsara and Roy, 2008). All nutrients estimated were reported on elemental percentage basis. Grain and stover yields were also estimated per hectare as well as hundred grain weights at grain moisture content of 15 %.Total dry matter (TDM) of the various plant parts were calculated as follows:

a. Formular for the calculation of the stover

$$TDM \ (Stover)\ per\ plot \quad = \frac{DMs\ X\ TFM}{FWs}$$

b. Formula for the calculation of the grain

$$TDM \ (Grain)\ per\ plot \quad = \frac{DMs\ X\ TFM}{FWs}$$

Where;

TDM = total dry matter weight

DMs = sub-sample dry matter weight

TFW = total fresh weight

FWs = sub-sample fresh weigh

Stover yield (kg/ha) = TDM (stover) x harvested area

Grain yield (kg/ha) = TDM (grain) x harvested area

Plate 13: Plate 12: Weighing of biomass with analog balance

Plate 14: Plate 13: Samples of dried biomass (stover) for weighing

3.6.2 Plants Height Measurement

Plants height was measured at 15 days interval. Three plants were randomly selected from each plot and plant height was measured from the plant base to the funnel (apical tip) of the youngest two leaves using a measuring tape. Plate 14 below showed the process of taking measurement of plant height.

Plate 15: Plant height at 28 days after planting

3.6.3 Number of leaves

Before cutting the fodder plant, the numbers of leaves were counted randomly from three plants in each plot. Data were collected weekly for eight weeks after germination.

3.6.4 Stem girth

Two months after planting, plant girth was measured 30 cm from the soil level with the use of a vernier caliper. Three measurements of each of the parameters were taken and then average of the three reading computed. Plate 15 below showed the process of taking plant stem diameter with vernier caliper.

Plate 16: Measuring stem diameter / girth

3.6.5 Leaf length

Leave length recorded every week from the date when the first plant emerged for a period of two months. This was done at a weekly interval started on 16th July and ended on 16th September 2015. Six maize plants were selected at random from each plot and tagged for growth measurements. All measurements were done using a meter rule to ±0.1 cm (Elings, 2000). Leaf length and width were measured on the youngest fully open leaf. Leaf length was taken from the apex to the stalk scar, while leaf width was measured at the widest part of the leaf. The leaf length and width were measured to obtain the leaf area. The leaf area was estimated as follows; Leaf length x maximum width x 0.75 (maize leaf calibration factor) (Elings, 2000).Plate 16 demonstrates the process of measuring leaf length.

Plate 17: Measurement of leaf length

3.6.6 Yield

Harvesting was done on 18th October 2015 and that was 10 weeks after planting. Before harvesting, plants were irrigated to wash away soil from leaves and stem. The entire plants on the plots were harvested by cutting at the ground level and weighted to represent the total fresh weight. A sub-sample of 6 plants were randomly selected and weighed. The plants were then separated into ears (cob + grains) and stovers (stem, leaves and husks). The plant parts i.e. ears and stovers were weighed and their weights recorded as fresh weight. The ears were further separated into cobs and grains by hand. The various plant parts were put in brown paper envelopes and then oven dried at 60°C for 48 hours to estimate their dry matter(Elings, 2000).

3.6.7 Nutrient uptake

Nutrient uptake was determined for maize (*Zea mays*)stover and grain. This was calculated from the nutrient concentrations obtained from the tissue analysis and oven-dry matter weight expressed in t/ha. Total C and N were measured on samples that were acidified to pH 1.5 to minimize NH volatilization, then air driedand ground, and finally combusted using a Carlo ErbaCN analyzer. The weight of the plant sample from each treatment was measured to determine the percentage reduction in mass. Masses of nutrients N and C in the windrows weredetermined (nutrient or C concentration × dry weight of the windrow), and the losses were computed asfollows:

$$\text{N. L (\%)} = \frac{\text{Initial Mass or Nutrient} - \text{Final Mass or Nutrient}}{\text{Initial Mass or Nutrient}}\ x\ 100$$

3.7 Compost Stability Experiment

A total of 128 litterbags (25cm x 25cm size)were sewed for the compost stability experiment. To quantify the stability of the applied composts, 20g of composts was packed in litterbags. Litterbags were closed by sewing. Two litterbags were buried in a randomly chosen ridge on each compost plot after ridge preparation. After the rainy season (end of October or 4 months of decomposition), two of the litterbags each from a corresponding ridge were sampled and removed and with the remaindertwo litterbags left in the ground for further decomposition. The remainder 2 litterbags were finally removed in 9 months' time of March 2016. The mass of sampled composts in litterbags were taken after air dried for 4 days. The compostswere further subjected to laboratory analysis for Total N, C and pH.The weight of the compost from each treatment was measured at the beginning day 1, end of 4th month and end 9th month of composting to determine the percentage reduction in mass

Plate 18: Empty litterbags prepared for the experiment

Plate 19: Sealed litterbags filled with organic amendments

3.8 Statistical analysis

Data on all parameters/response variables were subjected to analysis of variance (ANOVA) using the GenStat statistical package. Means were separated using the least significant difference (LSD) at 5 % level of probability.

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

This chapter presents results of the study which includes initial soil properties of the experimental field, results on vegetative/growth parameters, reproductive and above ground biomasses, results on soil samples, results on plant nutrient uptake, and results from compost maturity and stability experiment.

4.2 Initial soil properties of the experimental soil

The physiochemical properties of initial soil samples from the varied experimental plots are represented in Table 9. Initial soil bulk densities were not statistically significant ($p = 0.473$). However, the mean bulk density was 0.81 gcm^{-3} of the top soil (0 – 20 cm).

There was no significant difference in selected chemical properties (P, C, N, and pH) of soil samples taken prior to the application of amendments except C:N. However, mean nutrient concentrations of P, C and N were 12.06 ppm, 0.46 % and 0.02 % respectively. C:N ratio however, was significantly different among soil samples taken. The soil pH before the application of amendments ranged from 4.43 to 5.45 (acidic to moderately acidic) with a mean value of 4.73.

Table 8: Physiochemical properties of initial soil samples

Block	P (ppm)	Total C (%)	Total N (%)	C:N	pH	Bulk density (gcm^{-3})
1	12.76	0.48	0.05	9.58	5.45	0.76
2	11.45	0.48	0.02	23.79	4.43	0.96
3	12.70	0.50	0.01	25.77	4.54	0.73
4	11.33	0.38	0.01	21.96	4.58	0.80
Mean	12.06	0.46	0.02	16.8	**4.75**	0.81
p-value	0.13	0.45	0.52	0.013	0.38	0.47
LSD	1.58	0.18	0.05	7.73	1.43	0.35

4.3 Effects of amendments on soil chemical properties after 4 weeks of application

Table 10 shown results for week 4 after amendments application. There were significant influence on soil P, C and N content with the application of amendments. Uncarbonized compost (R0, M0 and S0) gave the highest increased in P value except NAP as compared to other compost and the control. Carbonized compost (R1, M1, and S1) gave the highest increased in the values of C as compared to other compost and the control. NAP increased N content higher than the compost but statistically similar. However uncarbonized compost (R0, M0, and S0) also increased N content better than the carbonized compost (R1, M1 and S1). Soil pH content was significantly increased with the application of amendments as compared to the control. Uncarbonized compost (R0, M0, and S0) significantly reduced C:N ratios as compared to carbonized compost (R1, M1 and S1)..

Table 9: Effect of amendmentson soil properties after 4 weeks of application of treatments

Treatment	P(ppm)	Total C (%)	Total N (%)	C:N	pH
R0	40.63	0.54	0.09	5.78	6.54
M0	45.73	0.46	0.10	4.33	7.17
S0	40.99	0.53	0.07	7.00	7.08
R1	26.76	1.14	0.06	17.19	5.82
M1	25.98	1.16	0.07	16.57	5.57
S1	24.80	0.95	0.05	17.87	7.15
G1	30.48	0.61	0.05	11.45	6.47
G2	23.70	0.71	0.07	9.24	6.30
NAP	47.47	0.95	0.11	8.45	5.92
C0	16.16	0.26	0.03	7.15	4.72
p-value	<.001	0.020	0.002	<.001	<.001
LSD	8.89	0.54	0.03	0.09	0.80

4.4 Effects of amendments on soil chemical properties after 12 weeks of application

Table 11 shown results for week 12 after amendments application. There were significant influence on soil P, C and N content with the application of amendments. Uncarbonized compost (R0, M0 and S0) gave the highest increased in P value except NAP as compared to other compost and the control. Carbonized compost (R1, M1, and S1) gave the highest increased in the values of C as compared to other compost and the control. NAP increased N content higher than the compost but statistically similar. However carbonized compost (M1) gave the highest increased in N content better than the uncarbonized compost (R0, M0 and S0) and the control. Soil pH content was significantly decreased with amendmentsat week 12 of application. Uncarbonized compost (R0, M0, and S0) significantly reduced C:N ratios as compared to carbonized compost (R1, M1 and S1).

Table 10: Effect of amendment on soil properties after 12 weeks of treatment application

Treatment	P (ppm)	Total C (%)	Total N (%)	C:N Ratio	pH
R_0	19.00	0.49	0.05	8.92	5.29
M_0	18.33	0.48	0.04	10.29	5.32
S_0	21.67	0.44	0.04	10.22	5.54
R_1	18.00	0.55	0.05	9.58	5.58
M_1	17.00	0.62	0.06	10.41	5.50
S_1	16.67	0.55	0.05	10.14	5.63
G_1	19.00	0.41	0.04	9.61	4.87
G_2	17.67	0.37	0.04	8.25	4.79
NAP	20.67	0.50	0.08	5.25	5.26
CO	13.33	0.24	0.02	8.95	4.72
p-value	0.001	<.001	<.001	0.007	<.001
LSD	3.04	0.11	0.01	2.21	0.24

4.5 Effects of amendments on maize plant height

Fig3 present results for maize plant height at 14, 28, 56 and 77 days after planting (DAP). Maize plant height was significantly influenced ($P > 0.05$ and $P > 0.001$) by the application of amendmentsat different stages of plant growth. There was uniform plant height at 14 DAP among all plants treated with amendments. At 28 DAP, NAP and M0 increased plant height higher as compared to the control which was similar to plant growth performance at 56 DAP and 77 DAP.Uncarbonized co-compost (R_0, M_0 and S_0) increased plant height at various growth stages as compared to other amendments except NAP which gave highest plant height at most stages.

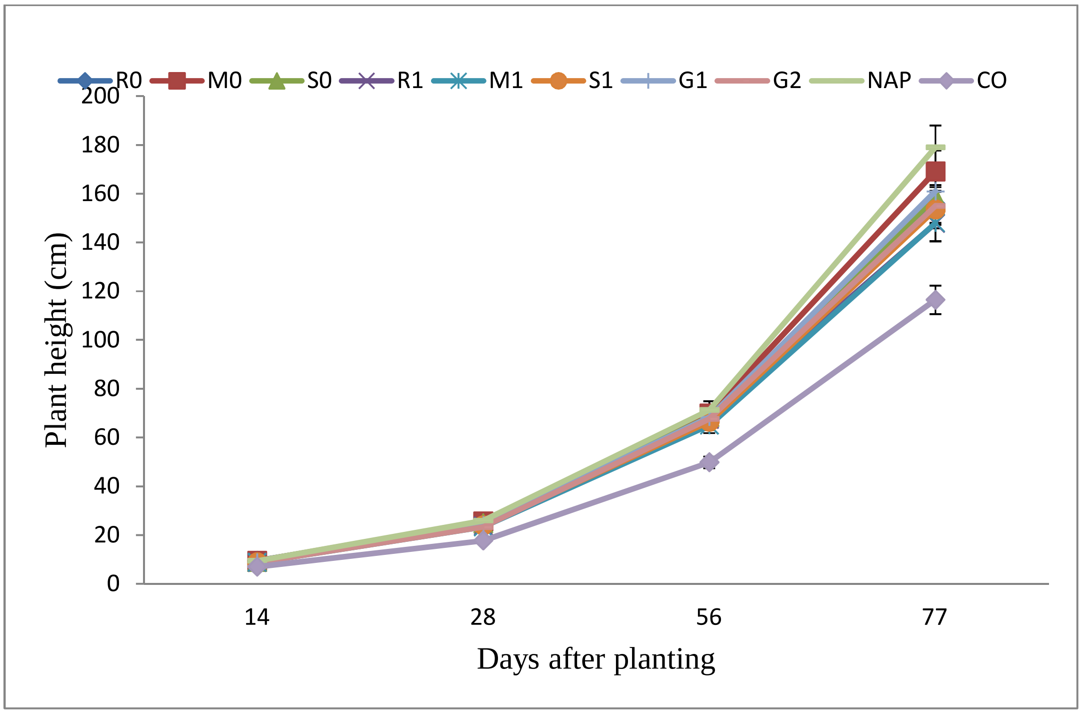

Figure 3: Effects of amendments on maize plant height at various stages of growth

4.6 Effects amendments on maize leaf area index (LAI)

There was an exponential increase in leaf area index from 14, 28, 56 and 77 DAP (Figure 4). NAP and M0 amendments resulted in significantly the highest leaf area indices at most stages of growth as compared to the other amendments but the control however gave the least. The LAI of uncarbonized compost (R0, M0, and S0) were appreciably higher than those of the carbonized compost and the multi-grow compost.

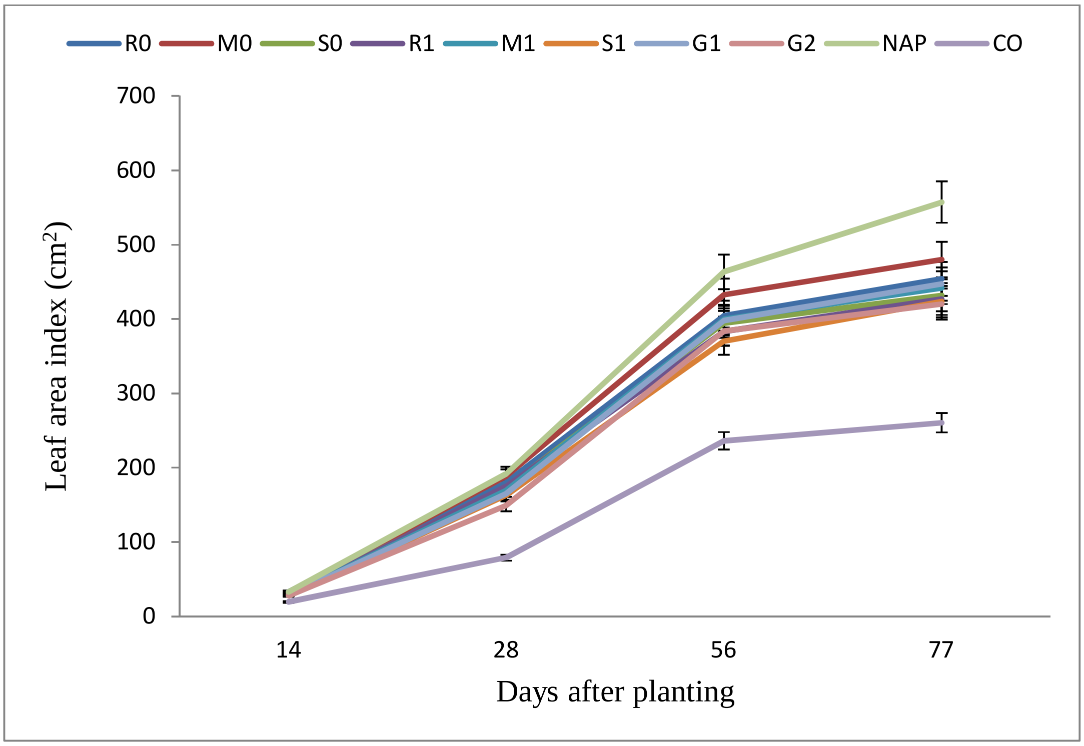

Figure 4: Effect of amendments on maize plant leaf area index

4.7 Effects of amendments on maize number of leaves

Application of the amendments on maize plants showed significant effect on the number of leaves at 14, 28, 56, and 77 days after planting (DAP).At 14 days, NAP and M0produced significantly highest number of leaves as compared to others and the least number of leaves wasrecorded under the control. At 28 DAP, NAP and uncarbonized compostproducedsignificantly highest leaf number as compared to the carbonized and the multi-grow compost which were however better than the control.At 56 and 77 days, NAP and the uncarbonized (R0, M0 and S0) gave average the highest number of leaves as compared to the carbonized and the multi-grow which also better than the control. Fig 5 showed effects of maize plant number of leaves at various stages of growth.

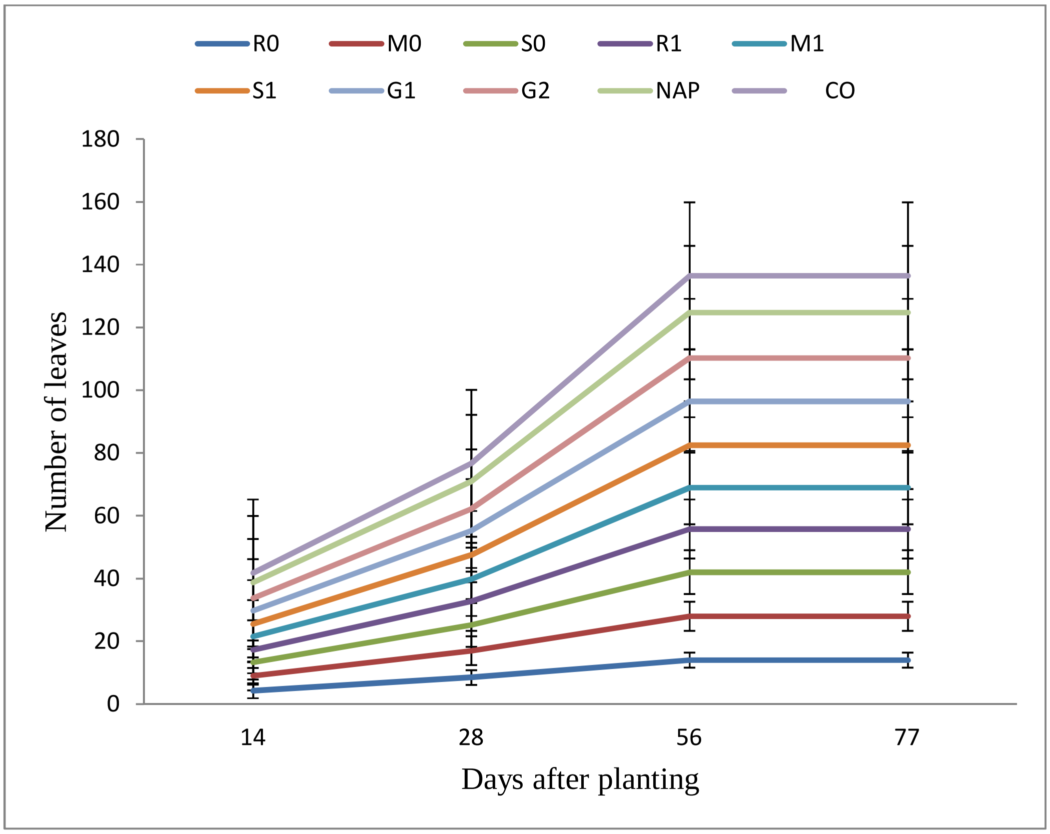

Figure 5: Effects of amendments on maize plant number of leaves at various stages of growth

4.8 Effects of amendments on plant girth, number of internode and internode length

At 77 days after planting, there were significant differences (P <0.05) on plant girth and number of internode. Plants treated with NAP and M0 produced significantly highest stem girth as compared to other amendments and the control. Plant treated with NAP, S_1, M_1, R_0 produced the highest number of internodes than the other amendments and the control. No significant difference was observed with internode length. However NAP gave the highest internode length and was statistically similar to the uncarbonized compost (Table 12).

Table 11: Effect of compost-biochar amendments and fertilizer on number of internode, length of internode and plant girth at 77 days after emergence

Treatment	**Plant girth (mm)**	**Internode no**	**Internode length (cm) @ 77 days**
R_0	16.50	14.00	15.00
M_0	19.00	13.75	15.00
S_0	16.75	13.50	13.75
R_1	16.75	13.75	14.25
M_1	16.00	14.00	13.75
S_1	17.00	14.00	14.00
G_1	14.25	12.75	13.75
G_2	15.25	13.00	13.50
NAP	19.75	$14^{.00}$	16.50
CO	11.00	10.25	11.00
P-Value	0.042	0.002	0.205
LSD	4.64	1.66	3.34

4.9 Yield data

4.9.1 Effects of amendments on total above ground non-edible and grain

The application of amendments significantly influenced fresh biomass weight, dried biomass weight, fresh edible weight (yield) and dried edible weight. On fresh biomass, NAP was numerically higher than other amendments and the control but not statistically different. On dried biomass, all plants treated with amendments performedbetter than the control. For fresh edible, all plants treated with M0, R1, and NAP performed best. However, all other treatments performed better than the control. On dried edible, all amendment performed better than the control. However, R0, M0, G2 and NAP seemed to be outstanding. Table 13 showed results for total above biomasses and grain.

Table 12: Effect of amendments on total above ground non-edible biomass and grain per hectare of maize

Treatment	Fresh biomass (t/ha)	Dried biomass (t/ha)	Fresh edible (t/ha)	Dried edible (t/ha)
R_0	20.35	10.73	9.57	8.32
M_0	21.62	11.77	10.47	8.26
S_0	17.75	9.74	8.26	7.52
R_1	19.55	9.15	8.78	7.72
M_1	19.48	9.15	9.03	7.30
S_1	18.68	8.96	9.00	7.05
G_1	21.45	8.52	10.88	6.48
G_2	19.18	9.37	9.35	7.70
NAP	26.80	10.30	14.00	8.77
CO	14.25	4.08	5.82	3.86
P-value	0.025	<.001	<.001	<.001
LSD	5.75	1.80	2.40	1.38

4.10 Effects of amendments on nutrient uptake by maize

Table 14 present nutrient uptakes by maize plant as influenced by the application of amendments. The incorporation of soil amendments had significant effect ($P > 0.001$) on the uptake of P, N, and C. Plant uptake of P was higher with M0 and NAP as compared to control. There was however no significant difference between amendments. Plant uptake of Nwas higher with NAP, S1, and M0 as compared to other amendments and the control. However there was no difference statically between amendments. Plant uptake of C was higher with all amendments as compared to the control.

R1, M1 and G2 had the highest C:N ratio as compared to other amendments and the control. On the other hand, NAP and S1 had the lowest C:N ratio compared to the control and other amendments.

Table 13: Effect of amendments on nutrient uptake by maize

Treatment	P (ppm)	Total C (%)	Total N (%)	C:N ratio
R_0	1.82	50.03	1.62	30.83
M_0	2.19	50.83	1.56	32.38
S_0	1.88	49.17	1.55	31.33
R_1	1.11	48.67	1.18	40.83
M_1	1.56	48.67	1.19	40.70
S_1	1.69	46.70	1.65	28.19
G_1	1.14	48.33	1.38	35.11
G_2	1.85	49.33	1.22	40.37
NAP	2.27	50.50	1.77	28.30
CO	0.59	27.60	0.01	37.44
P-value	**<.001**	**<.001**	**<.001**	**<.001**
LSD	**0.15**	**6.01**	**0.20**	**0.50**

4.11 Initial compost properties

Table 15 shown results for initial physiochemical properties of compost used for the experiment. There was significant difference among amendments on all physical and chemical properties measured. However, R0 recorded the highest P value of 79.39 ppm while S1 recorded the lowest P value of 39.37 ppm. M1 had the highest total C value of 54.39 % and R0 had the least value of 33.78 %. M0 had the highest total N of 2.84 % and S1 had the least of 1.37 %. S1 had the highest C:N ratio of 31.72 and M0 had the least value of 13.11. The highest pH value was 8.12 recorded under M1 and the least was 6.80 recorded under G2. The highest bulk density was 0.43 gcm^{-3} recorded under S1 and the least was 1.15 gcm^{-3} recorded under G1.

Table 14: Physiochemical properties of initial compost

Treatment	Avail P (ppm)	Total C (%)	Total N (%)	C:N	pH (CaCl$_2$)	Bulk density (gcm^{-3})
R0	67.58	33.78	1.90	17.83	7.25	0.22
M0	73.74	37.26	2.84	13.11	7.95	0.29
S0	79.39	37.82	2.10	19.02	7.85	0.24
R1	78.09	38.47	2.05	18.75	7.93	0.16
M1	68.97	54.92	2.06	26.72	8.12	0.30
S1	39.37	43.35	1.37	31.72	7.84	0.43
G1	64.00	38.40	2.46	15.70	7.20	0.15
G2	45.00	35.60	1.68	19.00	6.80	0.20
P-value	<.001	<.001	<.001	<.001	<.001	<.001
LSD	0.49	0.12	0.01	0.008	0.4847	0.05

4.12 Characteristics of compost analysis

Table 16 present results for chemical analysis of compost in litter bags after 9 months of decomposition. In P there was statistical difference among amendments. Uncarbonized compost (R0) had the highest value for P as compared to the least recorded under carbonized compost (S1). R1, M1 and S1 had the highest values for C as compared to other amendments but there was no difference between amendments. S1 had the highest C:N ratio as compared to other amendments. However M0 and G1 had the lowest C:N ratio as compared to other amendments. In pH values, there was no significant difference between amendments since all values were almost the same.

Table 15: Chemical analysis of compost in litterbags

Treatment	P (ppm)	Total C (%)	Total N (%)	C:N	pH
R_0	32.30	27.07	1.45	18.69	5.51
M_0	27.63	26.13	1.88	13.89	6.52
S_0	30.97	28.40	1.76	16.13	6.63
R_1	30.30	31.57	1.69	18.71	6.72
M_1	18.90	31.40	1.58	19.87	6.35
S_1	14.47	31.63	1.17	24.26	6.38
G_1	26.53	26.57	1.88	14.13	6.58
G_2	30.80	23.13	1.23	18.80	6.56
p-value	<.001	<.001	0.55	<.001	0.63
LSD	0.49	1.99	0.89	0.12	1.44

4.13 Decomposition rate of organic amendments used for the experiment

Table 17 below presents the rate of decomposition of organic amendments used for the experiment. There was significant difference (P > 0.05 and 0.001) in mass of organic amendments in October (four months of incorporation) and March (one year of incorporation) respectively. Uncarbonized compost (R0, M0) loss weight faster by 41.32% and 43.56%respectively in 9 months than carbonized compost (R1, M1 and S1) and the multi-grow compost (G1 and G2). However S1 reduced by only 26.87% by 9 months as compared to others.

Table 16: Rate of mass loss of compost at 4 and 9 months of decomposition

Treatment	Initial Wt. (g)	Oct. Wt. (g)	Mar. Wt. (g)	% Mass Loss
R_0	20.00	15.67	11.42	41.32
M_0	20.00	15.35	11.52	43.56
S_0	20.00	15.92	12.60	33.33
R_1	20.00	1.37	13.90	31.42
M_1	20.00	17.27	14.27	28.21
S_1	20.00	16.75	14.67	26.87
G_1	20.00	16.22	12.80	30.00
G_2	20.00	16.62	13.72	33.79
p-value	-	0.002	<.001	<.001
LSD	-	0.77	0.65	5.17

CHAPTER FIVE

5.0 DISCUSSION OF RESULTS

5.1 Introduction

This chapter discusses results or findings of the study. It include the effects of amendments on soil physical and chemical properties, soil nutrients,maize growth, above ground biomass, plant nutrient uptake and decomposition rate of organic amendments.

5.2 The effects of amendments on soil properties

All organic amendments applied significantly improved soil organic concentration and this effect wasmostly observed with uncarbonizedcompost (M_0, R_0 and S_0) than carbonizedcompost (R_1, M_1, and S_1) and the control except Normal Agricultural Practice (NAP). It has been reported that organic amendments particularly compost has considerable potential for soil improvement because of its unique physical, chemical, and biological properties and its interactions with soil and plant communities (Elad*et al.*, 2011). It is further believed that improvement in total porosity might be as a result of the improved soil aggregation, brought about by the improved soil organic matter content of the plots amended with the composts.Organic matter is known to improve soil physical properties (Aluko and Oyeleke, 2005) as also observed from the results of the study. This observation is also in agreement with the reports ofAdeleye*et al* (2010) who stated that application of organic amendmentsimprove and ameliorate several soil physical properties, such as bulk density, total porosity, penetration resistance and cohesion force. The organic carbon concentration in the treatments was found to be significantly different. The values indicated that all the organic materials could be used to potentially enhance the fertility status of the soil (Elings, 2000). This experiment clearly demonstrates that the addition of compost delivered the best short-term results with respect to soil quality. Soil pH wassignificantly enhanced and nutrient contents and nutrient availability were positively affected which was reflected in best plant growth and biomass yield of the compost treatment. Leroy *et al* (2007) mentioned that N mineralization from vegetable, fruit and garden compost is very limited in the short term. The residual N effect becomes visible after 4 to 5 years and repeated application will also improve soil physical properties. In this research, soil properties were determined after 5 months of compost application and this may be too earlyto determine the influence of compost on soil properties. Similarly, Erhart&Hartl (2010) and Diacono&Montemurro (2010) both pointed out that only a part of the N andP in compost is readily available for plant uptake and a large part needs to be mineralized.

A productive soil should have an organic matter content of at least 4 % out of which 2.32 % should be SOC (Aggelides*et al.*,2000). The low organic carbon recorded in some amendments during the experiment was due to the low inherent soil fertility, and possibly high soil temperature and aeration influencing faster microbial activity (breakdown). The application of carbonized and uncarbonized amendments could not raise the organic carbon content in the respective amended plots to the optimum (2.32 %). This suggests that apart from the inherent soil fertility and the prevailing climatic conditions, appreciable rate of increase in soil organic content will depend on the length of time that management is imposed.

5.2.1 pH

Significant increases in soil pH were found in association with all amendments compared with the control. Compost application significantly increased the soil pH. This is in agreement with Motsara and Roy(2008)) who reported an increase in soil pH on plots treated with compost. The increase in soil pH could be attributed to the reduction of exchangeable Al in the acidic soils, which is reflected in this study by the decrease in total exchangeable acidity.Initial soil pH was 4.92, which increased significantly following the addition of organic amendments up to a maximum of 7.17 (Table 11). The significant increases in soil pH may be attributed to the mineral ash content of the various organic materials and resulted in a liming effect raising the soil pH as reported in (Lehmann *et al*. 2003).The soils in this experiment were acidic with a pH between 4.77 and 5.38 (Table 12). Under such conditions, the availability of the base forming cations is limited because the soil solution is mostly occupied by Al and H_2^{1+}(Motsara and Roy, 2008). The increased soil pH could be attributed to the reduction of exchangeable Al, through Al precipitation or chelation of organic colloids. The findings of this study are in agreement with (Erhart&Hartl, 2010; Leroy *et al.*, 2007) where application of compost resulted in increased soil pH in acidic and slightly acidic soils through base-forming cations.

5.2.2 Soil Nutrient (Nitrogen and Phosphorus)

There was significant increased in soil nutrients (N and P) as a result of the organic amendments. Increases in soil N concentration were in the order of NAP>M_0>R_0>S_0>G_2>M_1>R_1>G_1>S_1>CO. These increases in soil nutrient content might be primarily associated with the nutrient content of the amendments which of course depend on the source and nature of the feedstock (Motsara and Roy, 2008)) and, for biochar, the pyrolysis process such as temperature, heating rate, duration. Increase in N content in soils amended with compost and biochar suggests the ability of these amendments to supply N because of their fairly high N content. The highest N level was observed in chemical fertilizer plots (NAP) as result of the NPK amendment imposed on these plots, which was later followed by a 'top dress' with sulphate of ammonia. The nitrogen content of these fertilizers made a significant contribution to the total N initially in the soil.Total nitrogen content after 4 weeks of treatment application ranged from 0.0367 to 0.1133 %.After harvest at 12 weeks, the soil total nitrogen ranged from 0.0271 to 0.0899 % (low to medium). Generally, as a result of nutrient uptake by the maize, soil total nitrogen content decreased in all the treatments after harvest (Table 11 and 12). Hanway (1962) observed that N tends to be depleted rapidly from the soil with cash grain farming such as maize.

Soil organic carbon contents were low (0.380 to 0.500) before the experiment and at week 4 ranged from low to high (0.263 to 1.160) while at week 12 ranged from low to medium (0.241 to 0.628). Carbonizedcompost (M_1, R_1 and S_1) recorded the highest C while the uncarbonized compost and mul-tigrow recorded the lowest (M_0, R_0, S0, G_1, G_2).

Results indicated high levels of available P in amended plots. The initial available P before the experiment ranged from 11.33 to 12.76 ppm and at 4 weeks after the application of the treatments ranged from 16.16 to 47.47 ppm while after harvest in 12 weeks ranged from 13.33 to 21.67ppm. The increased in P at week 4 could be attributed to the availability of P inputs from the amendments which contributed to high levels in the respective plots. Significant differences between amendments and the control were observed with respect to available P (Leroy *et al.*, 2007; Motsara and Roy, 2008).

5.2.3 Carbon-Nitrogen Ratio (C:N)

Initial averageC:N ratio was 11.11. For the soil amendments, only biochar co-compost significantlyincreased C:N ratio, while uncarbonized co-compost had no significant effect on C:N ratio. There wasno significant difference in C:N ratio between carbonized co-compost treatments indicating that the composted biochar quality did not change during the experiment. As expected, only biochar contributed to an increase of C:N ratio. On the other hand, uncarbonized co-compost had no or a negative effect on C:N ratio due to its higher N content corroborating the assumption that biochar would add especially organic C to soil and compost would provide especially N. Interestingly, the high Carbon to Nitrogen was as the result of the fact that more nitrogen was retained compared to carbon leading to the assumption that an amount of nitrogen might have been retained either physically by biochar or biologically by soil micro-organisms.

Generally, higher C:N ratios confirms results from Lehmann (2009) who related a higher biochar decomposition rate to higher O/C values and lower aryl C contents.

5.3 Effect of amendments on maize growth/vegetative parameters

The result of the study showed clearly the potential of uncarbonized co-compost and carbonized co-compost using different feedstock for improving maize vegetative performance. The amendments significantly influenced the plant height, stem girth, leaf length and width and number of leaves at 14, 28 and 56 days of planting respectivelyas compared to the control. This is in agreement with Aziz *et al* (2010) and Ogbonna*et al.* (2012), who both reported a significantly taller plants and larger leaves with compost application. Plants treated with uncarbonized compost M_0, S_0 and NAP were the tallest 56 days after planting and produced the largest leaves compared to the other compost amendments (Table 12). This could be attributed to the high nutrient content, especially M_0 which had high initial N concentration. Maize grown with G_1, G_2 had the smallest plants compared to the co-compost amendments. Even though these composts have a high initial N content it did not result in larger plants growth. The nutrients of these composts possibly were not made available for plant use or delayed in mineralization. These improvements in growth performance are consistent with other studies (Major *et al.,* 2010; Zhang *et al.,* 2016) and may be attributed to improved availability of nutrients and soil moisture.

Comparatively, the findings therefore suggest that uncarbonizedcompost amendments performed much better in all growth parameters than carbonizedcompost probably because of higher N concentration in uncarbonized compost (M_0) than carbonizedcompost. It has also been reported that nutrients availability in sufficient amount improves plant leaf area development (Ransom, 2013). All the plants treated with uncarbonized co-compost amendments gave higher number of leaves, stem girth and leaf area more than carbonized and control treatments. This confirmed the finding ofOwen(2015) that the application of compost contributed greatly to the plant growth when compared to control. This was also in line with the reports of Asai*et al.* (2009) that, though biochar possesses some essential elements required for plant growth but biochar can only be effective and improve plant growth when combined with other fertilizers (Blackwell *et al.*, 2010). Chan *et al* (2008) therefore gave a conclusion that biochar is not an actual fertilizer based on these observations. This can be explained by the low plant available nutrient content of the biocharand by a higher CEC and maybe also by a higher pH value but only during the growth period.Therefore, the beneficial compost effect for plantgrowth is either due to higher pH due to the factthat compost mineralization provides P and N more sustainablyfor plant growth.

5.4 Effect of amendments on maize above ground biomass

Total above ground biomass and yield were significantly influenced by the organic amendments and inorganic fertilizer relative to the control. Fresh and dry biomasses weresignificant at 5 % probability level similar to total yield (edible part). However no significant influence of treatments was observed with sampled fresh and dry edible. The results showed that highest values of above ground biomass and grain yield of maize were observed in plants treated with uncarbonized co-compost but better than carbonized co-compost and control except Normal Agricultural Practice (NAP). The improvement in the performance of maize could be attributed to high initial value of N in uncarbonized co-compost as compared to carbonized co-compost and control (Table 13). The results is in agreement with Hitchings (2012) who reported that high N fertilization resulted in increasing above ground dry biomass and which is also in line withVanlauwe*et al* (2010) who reported that increasing the levels of nitrogen in the soil under different soil and management condition showed increasing above ground dry biomass. The increase in above ground dry biomass of maize could reflect the better growth and development of the plants due to balanced and more availability of nutrients throughout the growing period. The observed increase in maize yield with application of uncarbonized co-compost compared to the carbonized co-compost and the control except NAP demonstrates that co-composting contributes to a better nutrient composition.

Although carbonizedco-compost was not as effective as uncarbonized co-compost but nutrient such as potassium which is usually limiting in poor soils have been reportedly supplied by the ash from carbonized. Variation observed on the growth parameters with regards to different feed stocks(rice husk, corn cobs, poultry manure, and sawdust, charcoal) used for the co-compost production could be due to variations in their nutrient compositions. A fraction of the nitrogen and other nutrients in the amendments become available in the first year of application (Eghball*et al.*, 2002) others remain in the soil for soil improvement over a long time. The finding of Van Zwiten*et al* (2010) also suggested that while biochar may not provide a significant source of plant nutrients, they can improve the nutrient assimilation capability of crops thereby positively influencing the soil environment.

The findings indicate that application of all organic amendments promoted growth and productivity of maize. The carbonized and uncarbonized co-compost used in the study may have served as bulking agent by improving soil structure, porosity, aeration, and root penetration (Calzolari*et al.*, 2009). This enhanced maize root penetration and aeration in the rhizosphere, thus enabled absorption of water and essential nutrients from soil to improve the *Zeamay's* growth and development.

5.5 Maize plant nutrient uptake

N uptake by maize plant was influenced by the application of amendments. Uncarbonized co-compost had significant increased effect on N uptake than carbonized co-compost and the control. Normal Agricultural Practice (NAP) and however, recorded significant increase in N uptake as compared to other amendments of carbonized and uncarbonized co-compost.

Generally,nitrogen contents in maize weremore in uncarbonizedco-compost based amendments than carbonized co-compost and the control except NAP. The uncarbonized co-compost(R_0, M_0, and S_0) could have made more available Nto the plant than carbonized co-compost and conventional compost(R_1, M_1, G_1, and G_2) as there was variation among N content in amendments. The observation is therefore similar toAmanullah and Yassin (2006) where N content in maize plant was high due to increasing rate of N fertilization. Generally the lower uptake of N in the experimentmight be due to volatilization of ammonical-N and immobilization.It was reported that soil NO_3- concentration regulates crop N uptake, not only under situations of low but also under situations of high soil NO_3^- concentration, when crop N is above its critical N concentration and where excess N accumulation in plants occurs. The regulation of whole plant and crop N uptake in heterogeneous soil remains poorly understood (Tischner, 2000; Devienne-Barret*et al.,* 2000).

The amount of N taken up by the maize plant has a major impact on overall crop growth rate. The dependence of crop growth on crop N relies on several processes which include leaf photosynthesis–N relationships, the distribution of N between leaves, leaf expansion and positioning and subsequent impacts on light interception (Gastal and Limaire, 2002).

5.6 Weigh losses ofuncarbonized and carbonized compost after 4 and 9 months of decomposition

There was significant difference ($P > 0.05$ and 0.001) in mass of organic amendments sampled after 4 months of application(October) and after 9 months of application (March) respectively. Uncarbonized co-compost (R_0, M_0 and S_0) lost weight faster than carbonized co-compost (R_1, M_1 and S_1) which was also faster in weight reductionthan the control in October and March respectively. The initial weight was 20g per litterbag, at the end of the experiment in 4 months (July to October) ranges from 15 to 17g per litterbag, representing mass lossfrom and in 9 months' time (July to March) ranges from 11 to 14 representing 42.87to 26% mass loss. The carbonized co-compost had wider C:N ratios ranging from 18.75 to 31.70 and its direct application to soil might have caused immobilization of the applied N (Table 9). It is well established fact that N availability can be a limiting factor for soil microorganisms responsible for decomposition of organic material (Mary *et al.*,1996). Organic material having wider C:N ratiorequires additional application of N while undergoing microbial decomposition.

It was observed that organic amendments that had high amount of organic solid waste (M_0) experienced high volume reduction which also depicts high rate of degradation leading to loss of organic carbon in the form of carbon dioxide and water. This was in agreement with Pilar*et al* (2015) who reported 50% loss in volume when composting manure.

Another reason accounted for the differences in the mass of the amendments was the value of the C:N ratios of various composts. High C:N ratios make the process as there is an excess of degradable substrates for the microorganisms. But with a low C:N ratio there is an excess of N per degradable C and inorganic N is produced in excess and can be lost by ammonia volatilization or by leaching from the composting mass as explained by Goyal*et al*(2005). There was also a general decreased in C:N ratios in respect of all amendments indicating decomposition as reported by Sellami*et al*2008) that a reduction in C:N ratio implies the degree of humification of organic matter. It is therefore supported by Bernal *et al*(2009)that decomposition progressed due to losses of carbon mainly as carbon dioxide, the carbon content of the compostable material decreased with time and N content per unit material increased which resulted in the decrease of C:N ratio. The researchers reported that a C:N ratio below 20 was assumed to be indicative of maturity of compost and a ratio 15 or less is preferable (Bernal *et al.,* 2009; Goyal*et al* 2005). On the other hand, some researchers (Sellami*et al.,* 2008) reported that C:N ratio alone is not sufficient criteria to determine the compost maturity and it is very establishing compost maturity (Goyal*et al.,* 2005).

Differences in the mass of the amendments could be the influenced of the pH value during the experiment. Initial pH ranges from 6.8 to 8.31 (Table 9) and the final pH ranges from 5.5 to 6.72 (Table 20). Primarily pH can be used to determine the process of decomposition of organic material (Motsara and Roy, 2008). Compost microorganisms operate best under neutral to acidic conditions, with pH in the range of 5.5 to 8. During the initial stages of decomposition, organic acids are formed. The acidic conditions are favorable for growth of fungi and breakdown of lignin and cellulose. As composting proceeds, the organic acids become neutralized, and mature compost generally has a pH between 6 and 8.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATION

6.1 Introduction

This chapter summarizes the research findings, conclusions and gives recommendation and suggestions for further research and for curriculum development.

6.2 Conclusions

Agriculture activities in Ghana arechallenged by low productivity as a result of the declining soil fertility. Inorganic fertilizers are also expensive and farmers cannot afford adequate amount to supply on their fields. An alternative to inorganic fertilizers is the use of compost which is less expensive and environmental friendly to restore soil fertility. Farmers can use plant and animal remainswithin their reach for composting. This study is therefore focused on the efficacy of organic amendments on the growth and yield of maize under uncarbonized and carbonized co-compost soil amendments. It also seeks to determine the rate of decomposition of applied organic amendments over time and to measure the rate of change of soil properties with the application of organic amendments. Among specific findings of the research were;

Chemical properties of compost shown high values of P, C and N as observed with S0, M1, and M0 amendments respectively.C:N ratios of compost were within normal range of 15 to 25 with most amendments except M1 and S1 which were extremely high.

Initial chemical properties of soil showeda very low concentration of P, C and N with very strongly acidic condition. After 4 weeks of amendment application, there was positive increase in soil concentration of P, C and N with compost and the NAP than the control. Uncarbonized compost (M0, R0, and S0) increases soil N, P and C concentration faster than carbonized co-compost (M1, RI and S1) and Multi-grow compost.Averagely, uncarbonized compost positively enhanced soil pH better than carbonized co-compost and multi-grow compost.Compost application significantly increased soil pH due to reduce exchangeable acidity and the increase levels of exchangeable bases.

Compost application significantly improved plant growth and yield of maize compared to the control. M0 and NAP resulted in higher plant girth, fresh biomass, dry biomass and fresh yield than other compost and the control.Compost with high N concentration contributes to plant vegetative growth and high yield of maize than compost with very low N concentration. Farmers therefore would benefitusing compost as an alternative for the expensive inorganic fertilizers or the use of no inputs.

At week 12, carbonized compost (R1, M1, and S1) significantly retained N and C concentration in soil than uncarbonized compost.Plant uptake of P, N and C was higher with uncarbonized compost (M0) and more than with other compost.

Percentage decrease in P, C and N content after nine months of decomposition was higher with S1, R0 and M0.High rate of mass losses of compost after nine months of decomposition was observed with R0 and M0. C:N ratio decreases with uncarbonized compost amendments and increases with carbonized co-compost amendments.

This experiment clearly demonstrates that the addition of uncarbonized compost delivered the best short-term results with respect to soil quality. Organic amendments that has high amount of organic solid waste experience high volume reduction which also depicts high rate of degradation leading to loss of organic carbon.The feedstock's characteristics of compost therefore determine the rate of decomposition and the nutrient compositions of the amendment.This research has indicated that uncarbonized and carbonizedcompost has beneficial effects on soil properties, plant growth and yield.

6.3 Recommendations

- Further studies are required to optimize the combination of biochar compost or non biochar compost with inorganic fertilizer in agricultural activities.
- Long term studies of the treatments used in this study should be carried out to further ascertain their effects on the physico-chemical properties of the soil.
- However, further research is necessary to determine the combined effect of co-compost and inorganic fertilizer in crop yield between the various amendments.
- Subsequent research should take field variation into account and have detailed information on the nutrient content and quality of the plant and animal materials used in the composting process.

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APPENDICES

Appendix A:Output of GenstatAnalysis of variance on stem diameter

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	196.23	21.80	1.99	0.076
Residual	30	328.75	10.96		
Total	39	524.97			

Appendix B. Output of GenstatAnalysis of variance on plant height at 14 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	10291.5	1143.5	2.01	0.074
Residual	30	17089.2	569.6		
Total	39	27380.8			

Appendix B1:Output of GenstatAnalysis of variance on plant height at 28 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	9	8.952250	0.994694	115.89	<.001
Residual	30	0.257500	0.008583		
Total	39	9.209750			

Appendix B2:Output of GenstatAnalysis of variance on plant height at 56 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	9468.5	1052.1	3.24	0.007
Residual	30	9749.2	325.0		
Total	39	19217.8			

Appendix B3:Output of GenstatAnalysis of variance on plant height at 77 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	2490.14	276.68	18.14	<.001
Residual	30	457.70	15.26		
Total	39	2947.83			

Appendix C:Output of GenstatAnalysis of variance on Dry edible

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	25669	2852	1.47	0.206
Residual	30	58351	1945		
Total	39	84020			

Appendix C1: Output of GenstatAnalysis of variance on sample fresh biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	111942	12438	2.35	0.038
Residual	30	158718	5291		
Total	39	270659			

Appendix C2:Output of GenstatAnalysis of variance on Total biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	368.26	40.92	2.58	0.025
Residual	30	476.56	15.89		
Total	39	844.82			

Appendix C3: Output ofGenstatAnalysis of variance on total edible (yield)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	156.746	17.416	6.29	<.001
Residual	30	83.005	2.767		
Total	39	239.751			

Appendix D:Output of GenstatAnalysis of variance on leaf length 77DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	1522.88	169.21	12.78	<.001
Residual	30	397.34	13.24		
Total	39	1920.22			

Appendix D1:Output of GenstatAnalysis of variance on leaf length 28DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	1193.120	132.569	39.48	<.001
Residual	30	100.737	3.358		
Total	39	1293.858			

Appendix E:Output of GenstatAnalysis of variance on leaf width 77DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	20.3390	2.2599	12.54	<.001
Residual	30	5.4050	0.1802		
Total	39	25.7440			

Appendix E1:Output of GenstatAnalysis of variance on leaf width 28DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	7.65225	0.85025	15.39	<.001
Residual	30	1.65750	0.05525		
Total	39	9.30975			

Appendix F:Output of GenstatAnalysis of variance on number of leaves 77DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	20.1000	2.2333	13.40	<.001
Residual	30	5.0000	0.1667		
Total	39	25.1000			

Appendix G:Output of GenstatAnalysis of variance on weight of compost on March

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	7	42.3872	6.0553	30.23	<.001
Residual	24	4.8075	0.2003		
Total	31	47.1947			

Appendix G1:Output of GenstatAnalysis of variance on weight of compost on October

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	7	10.7950	1.5421	6.20	<.001
Residual	24	5.9650	0.2485		
Total	31	16.7600			