UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECTS OF INDIGENOUS ORGANIC MATERIALS FOR SOIL FERTILITY RESTORATION ON PRODUCTIVITY OF MAIZE (*Zea mays* L.) IN THE GUINEA SAVANNAH ZONE

B Y

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THESIS SUBMITTED TO THE DEPARTMENT OF AGRONOMY, FACULTY OF AGRICULTURE, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

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. Work of others which served as sources of information have been duly cited by reference to the authors.

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ABSTRACT

A pot and field experiments were conducted to determine the optimum planting date after incorporation of organic materials and the effects of indigenous organic materials on maize grain yield and yield components. The pot experiment was a 4 × 5 factorial experiment consisting of 4 Organic materials: biochar, rice straw, rice husk and groundnut shells of weight 156.2 g and 5 days of incorporations of organic materials (7, 14, 21, 28 and 35). The experiment was laid out in a randomized complete block design and replicated 3 times with surface area of each pot being 0.0314 m^2. The pot experiment results indicated that the parameters assessed were significantly influenced ($p \leq 0.05$) by the application of the organic materials and planting dates. Biochar and Groundnut Shells applications enhanced vigorous vegetative growth (plant height, leaf count) and were at par. Maximum total dry matter weight was recorded with Biochar and Groundnut Shells. 21, 28 and 35 days after incorporation of the organic materials gave the best performance in growth parameters and total dry matter weight. Optimum planting dates was observed at 21 days after incorporation of the different organic materials. The field trial was a 4×3×3+1 factorial experiment consisting of the same 4 organic materials as in the pot experiment at 2.5, 5 and 7.5 t ha^{-1} dry matter basis, 3 fertilizer grades (0-0-0 kg NPK ha^{-1}, 45-30-30 kg NPK ha^{-1} (1/2 NPK) and 90-60-60kg NPK ha^{-1} (FNPK)) and a control (non-fertilized). It was laid in a randomized complete block design with 4 replications. Results showed that application of organic materials with and without inorganic fertilizer significantly increased maize productivity. Vigorous vegetative growth was observed with the application of 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + 1/2 NPK, 7.5 t/ha Groundnut Shells + FNPK, 7.5 t/ha Groundnut Shells + 1/2 NPK, 5 t/ha Biochar + FNPK, 5 t/ha Biochar + 1/2 NPK, 7.5 t/ha Rice Husk + FNPK, 7.5 t/ha Rice Husk + 1/2 NPK, 7.5 t/ha Rice Straw + FNPK and 7.5 t/ha

Rice Straw + Y2 NPK. Applications of 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + Y2 NPK, 7.5 t/ha Groundnut Shells + FNPK, 7.5 t/ha Groundnut Shells + Y2 NPK, 5 t/ha Biochar + FNPK, 5 t/ha Biochar + Y2 NPK, 7.5 t/ha Rice Husk + FNPK, 7.5 t/ha Rice Husk + Y2 NPK, 7.5 t/ha Rice Straw + FNPK and 7.5 t/ha Rice Straw + Y2 NPK enhanced grain yield and yield components at harvest. The regression analysis showed that cob weight, 100 seed weight and stover weight at harvest determined grain yield. The soil amendments affected the soil pH, organic carbon content, the major soil nutrients (nitrogen, phosphorus and potassium) and the soil texture appreciably at harvest. All the organic amended treatments influenced soil productivity over the control and consequently enhanced higher maize yields. The organic nutrient management strategy fit into the status of the resource poor farmers in the Guinea savannah zone.

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DEDICATION

I dedicate this work to my parents Mr. and Mrs Osman. To my siblings Maria, Rashiid and Ridwan for giving me the love and care I needed. You all hold a special place in my heart.

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CHAPTER 1: INTRODUCTION

1.1 Background

Maize (*Zea mays* L.) is the most important cereal crop of the world, grown in irrigated and rain-fed areas (Hussan e*t al.*, 2003). It is a rich source of food, fodder, feed for animals and provides raw material for the industry. Maize can be processed into a wide range of foods and beverages, which are consumed as breakfast, main meals or snacks. It is also a main source of carbohydrates for poultry industries in Ghana.

Maize yield is below its yield potential compared to other maize producing countries (MoFA, 2010). Soil fertility depletion is a major factor militating against crop yields in Ghana (Issaka *et al.*, 2011). Low inherent soil fertility has been identified as a major cause for low rice yield in Ghana (Buri *et al.*, 2009; Issaka *et al.*, 2009; Abe *et al.*, 2010). Nyalemegle *et al.*, (2009) attributed the decline in rice yields to low inherent soil fertility, which is partly a result of low levels of soil organic matter. Maobe *et al.* (2010) reported that maize grain yield is constrained by inadequate nitrogen supply caused by insufficient application of fertilizers that are costly and unaffordable in smallholder farming. Mineral fertilizers to boost crop production are expensive and sometimes unavailable (Issaka *et al.*, 2012).

However, there are various organic materials that have the potential of effective agronomical use in Ghana (Issaka *et al.*, 2011). Fening *et al.* (2005) reported that there is an increasing interest in using crop residues for improving soil productivity which can reduce the use of external inputs of inorganic fertilizer. These crop residues are in sufficient abundance in farmers' fields at the end of a growing season and play an important role in soil fertility management through their short term effects on nutrient supply and longer term contribution to soil organic matter (Karanja *et al.*, 2006). Several workers including JIRCAS (2010) and Nakamura *et al.* (2012) have reported on the quantity, quality and distribution of various organic materials in Ghana. Issaka *et al.* (2012) concluded on the wealth of indigenous materials available in Ghana that can be used to significantly improve the fertility of the soil. Samy *et al.* (1997) showed that there was good potential for organic based rice farming with a combination of organic fertilizers to attain maximum yields. Sole application of organic materials or in combination with mineral fertilizer increased rice yields over the control (Issaka *et al.*, 2012).

Timing of application of organic materials is a fundamental element to maximizing nitrogen use efficiency in organic materials. Thomsen (2005) stated that management of manure fertilizers is difficult primarily because organic manures are affected by timing of incorporation and distribution. Havlin *et al.* (2005) noted that 50 to 75% of total nitrogen contained in manure is organic and needs to undergo mineralization. However, studies fall short of elucidating the optimum timing of planting after the incorporation of organic materials and the best material options for resource poor farmers.

1.2 Relevance and Objectives of the Study

Northern Region soils are fragile due to their Kaolinite clay-based constitution; as such there is the need to build the buffer capacity of these soils through increasing the level of organic matter. Adequate soil organic matter buffers the soil against drastic changes in soil pH, increases the exchange sites for storage and release of nutrients (CEC), moderates soil temperature, improves the physical base of the soil by increasing its resilience to soil structure deterioration and soil degradation. Organic matter is the source of about 90-95% of the nitrogen in unfertilized soils. Organic matter can be the major source of both available phosphorus and available sulphur when soil humus is presented in appreciable amounts.

The use of locally available materials for crop improvement is an option that can be fully exploited to improve crop production. The use of organic materials (such as rice straw, rice husk, biochar and groundnut shell) as soil amendments for agricultural practices is rarely used in Ghana. Large amounts of plant residues that can be used as soil amendments are annually generated through farming. These residues include maize stover, rice husk, rice straw, millet or sorghum resulting from annual production of these crops. The objectives of the study were therefore to determine:

1. The best commonly available organic materials for maize production on the farmers' field in Northern region.
2. The optimum time for planting after the incorporation of organic materials.
3. The synergistic effect between the organic materials and inorganic fertilizer on the growth and yield of maize.

CHAPTER 2: LITERATURE REVIEW

2.1 Climate Change and Agriculture

Climate change depicts the alternations in climatic conditions prevailing in an area. These include increasing temperatures, emissions of greenhouse gases and fluctuating rainfall patterns. Climatic variability, together with increase in atmospheric temperature and carbon dioxide has a lot of implications in the agricultural sector. Oseni and Masanrambi (2011) noted that climatic variability has been and continues to be the principal source of fluctuation in global food production in the developing countries.

Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce desirable crops yields while encouraging weed establishment and pests' proliferation. Changes in precipitation (rainfall) patterns can increase short-term crop failures and long-term production declines. The overall impact of climate change on agriculture is negative and threatening global food security. The impact of climate change include yields declines for important crops, varying effects on irrigated lands across regions of the world and additional price increment for most important agricultural crops like maize, rice and soybeans (FAO, 2007). Oseni and Masanrambi (2011) noted that the African rain-fed agriculture is the most vulnerable sector to climate variability and the potential impacts of climate change on agriculture are highly uncertain.

Agriculture is a sector where mitigation actions have strong potential co-benefit for sustainable development. Most of the mitigation potential from agriculture can be achieved through soil carbon sequestration. Mitigation potentials of biochar were estimated to be as high as 12% of current anthropogenic carbon dioxide emissions (Woolf *et al.*, 2010). With requisite physical and chemical properties, biochar can offer potential value to crop productivity through dynamic or reversible interactions with nutrients and soil mineral particles. Productivity improvement of existing agricultural land has the potential to ease pressure on biodiversity and carbon rich natural ecosystems.

Chun *et al.*, (2004) reported that biochars generated by pyrolyzing wheat residues at temperatures ranging from 300°C to 700°C removed benzene and nitrobenzene (organic contaminants) from waste water. Similarly, biochars produced from green waste removed atrazine and simazine from aqueous solution (Zheng *et al.*, 2010). Straw-derived biochar was found to be an excellent, cost-effective substitute for activated carbon to remove dyes from waste water (Qiu *et al.*, 2009). Broiler litter manure biochar enhanced the immobilization of heavy metals including cadmium (Cd), copper (Cu), nickel (Ni), and lead (Pb) in soil and water (Uchimiya *et al.*, 2011). Yao *et al.*, (2011) reported that biochar derived from anaerobically digested sugar beet tailings removed 73% of phosphate from the tested water. Biochar has surface area and porosity which are significant in improving water holding capacity, adsorption and nutrient retention (Sohi *et al*., 2010; Chintala *et al.* 2013). Amonette and Joseph (2009) indicated that biochar can affect soil structure, texture, porosity, particle size distribution and density, hence can improve aeration, water storage capacity and microbes, and nutrient availability in the root zone of plants. Biochar application led to changes in soil pH, electrical conductivity (EC), cation exchange capacity (CEC) and nutrient availability (Liang *et al.*, 2006; Gundale and DeLuca, 2007; Warnock *et al.*, 2007). Biochar reduced nitrogen leaching and improve nitrogen use efficiency (Steiner *et al.*, 2008; Widowati *et al.*, 2012; Chintala *et al.*, 2013).

2.2 Maize Taxonomy, Origin and Biology

Maize belongs to the Graminae family, sub-family Panicoideae, tribe Maydeae, genus *Zea* and species *mays*. Maize is not only a major cereal in the present-day world, but it has been one of the basic food crops since the fifteenth century. Nevertheless, the origin of maize has been a source of controversy. One school had it that maize descended from the wild plant teosinte and another that the cultigen was derived from hypothetical wild maize.

Maize is a monoecious annual crop that grows tall with an overlapping sheaths and broad conspicuously distichous blades (Rouanet, 1999). Maize plants have staminate spikelets in long spike-like racemes that form large spreading terminal panicles known as tassels and pistillate inflorescences in the leaf axils, in which the spikelets occur in 8 to 16 rows, approximately 30 cm long, on a thickened, almost woody axis (cob). The whole structure (ear) is enclosed in numerous large foliaceous bracts and a mass of long styles (silks) protrude from the tip as a mass of silky threads. Pollen is produced entirely in the staminate inflorescence and ear, entirely in the pistillate inflorescence. Maize is both self and cross pollination. The key agent of pollination is wind (Rouanet, 1999).

Maize requires a lot of light and fairly high temperature for optimum yield production. Its mechanism for assimilating carbon gives it a considerable scope for synthesizing starch provided it is not short of solar energy.

2.3 Maize Production in Ghana

Maize is the most important cereal crop in Ghana grown in all parts of the country mostly under rain-fed conditions. Maize cultivation is very high in the Brong Ahafo, Ashanti and Northern regions of Ghana (Angelucci, 2012). Maize is cultivated twice in the Brong Ahafo and Ashanti regions where they experience two rainfall patterns but once in a year in the northern regions. In Ghana, maize is produced predominantly by smallholder resource poor farmers under rain-fed conditions (SARI, 1996).

White maize is the common type of maize produced in Ghana while the imported yellow maize is used mainly as poultry feed. Morris *et al.* (1999) noted that maize has been cultivated in Ghana for several hundred years. Introduced in the late 16th century, maize established itself as an important food crop in the southern part of the country. Maize attracted the attention of commercial farmers, although it never achieved the economic importance of traditional plantation crops such as oil palm and cocoa. Over time, the eroding profitability of many plantation crops served to strengthen interest in commercial food crops including maize. Maize is the most important staple crop in Ghana and accounts for more than 50% of total cereal production (Akramov and Malek, 2012). Maize is the most important cereal crop on the domestic market in Ghana; it is the 7th largest agricultural commodity in terms of production value over the period from 2005-2010 accounting for 3.3% of total agricultural production value globally (FAO, 2012). The bulk of maize produced goes into food consumption and is the most important crop for food security. The development and productivity of the livestock and poultry sectors also depend on the maize value chain since maize is a major component of poultry and livestock feed. Akramov and Malek (2012) noted that maize is the second most important commodity crop in the country after cocoa. Maize is the most important cereal crop produced in Ghana and it is also the most widely consumed staple food in Ghana with increasing production since 1965 (FAO, 2008). Maize average yield registered by the Ministry of Agriculture in 2010 was 1.9 Mt/ha against an estimated achievable yields of around 2.5 to 4 Mt/ha (MoFA, 2010). Under traditional production methods and rain fed conditions, yields are well below their attainable levels. Generally, maize yields in Ghana average approximately 1.5 Mt/ha. However, yields as high as 5.0-5.5 Mt/ha can been realized by farmers using improved seeds, fertilizer, mechanization and irrigation.

2.4 Economic Importance of Maize

Maize is the most important cereal crop produced in Ghana and it is also the most widely consumed staple food in Ghana with increasing production since 1965 (FAO, 2008).

Maize is a rich source of food, fodder, feed and provides raw material for the industry. The per capital consumption of maize in Ghana in 2000 was estimated at 42.5 kg (MoFA, 2000). SRID (2007) estimated national consumption of maize to be 943000 Mt in 2006. Hussan *et al.*, (2003) noted that maize was the most important cereal fodder and grain crop grown under both irrigated and rain-fed agricultural systems in the semi-arid and arid tropics.

Morris *et al.*, (1999) documented that maize in Ghana is consumed in a variety of forms. In the north, it is commonly eaten as a thick gruel, similar to the way that sorghum and millet are consumed. In the south, it is frequently used to prepare porridges and more solid dishes such as 'akpele' made from fermented or unfermented dough. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled and plays an important role in filling the hunger gap after the dry season. In addition, its products like corn starch, corn flakes, gluten germ-cake, lactic-acid, alcohol and acetone are either directly consumed as food or used by various industries like paper textile, foundry and fermentation. Maize and other cereals constitute important sources of carbohydrates, proteins, vitamin B and minerals (Iken *et al.*, 2002). Maize grains have great nutritional value as they contain 72 % starch, 10 % protein, 4.8 % oil, 8.5 % fibre, 3.0 % sugar and 1.7 % ash (Chaudhary, 1983).

2.5 Challenges Facing Maize Production

Availability of adequate rainfall is by far the most limiting factor in maize production in Sub-Saharan Africa (CIMMYT, 1988). Kamara *et al.*, (2005) added that intermittent drought is implicated among the major constraints limiting the production of maize in the Guinea Savannah of West Africa. Bolonos and Edmeades (1993) estimated that 80% of the maize crop suffers periodic yield reduction due to drought stress. Drought at flowering and grain filling period may cause losses of 40-90% (Menkir and Akintunde, 2001). Low soil fertility is also among the major constraints limiting the production of maize in the Guinea Savannah of West Africa (Kamara *et al.*, 2005).

Although maize is of great economic importance in Ghana, its production is hindered by a lot of factors. Some of the important limiting factors to maize production in Ghana are poor inherent soil fertility, low capitalisation, price fluctuation, disease and pest attack, poor storage facilities and inefficiency of resources utilization in Ghana. In Ghana, crop response to nitrogen response on depleted soils that have been continuously cropped can be twice as high as on soils with high natural fertility that have laid fallow for a number of years (Edmeades *et al.*, 1991). FAO (2005) pointed out that fertilizer nutrient application in Ghana is approximately 8 kg/ha while depletion rates range from about 40 to 60 kg of nitrogen, phosphorus, and potassium (NPK)/ha/ yr and among the highest in Africa.

2.6 Nutrient Depletion in Soils

The extent of natural soil-nutrient depletion in Africa's agricultural land is high. Stoorvogel and Smaling (1990) indicated that an average of 660 kg N/ha, 75 kg P/ha and 450 kg K/ha have been lost during the last 30 years from about 200 million hectares of cultivated lands in 37 countries of Sub-Saharan Africa excluding South Africa. This is equivalent to 1.4 t of urea per hectare, 375 kg of triple superphosphate (TSP) per hectare or 0.9 t of phosphate rock (PR) per hectare of average composition and 896 kg of potassium chloride (KCl) per hectare during this period. These figures represent the balance between nutrient inputs (in fertilizers, manure, atmospheric deposition, biological nitrogen fixation (BNF) and sedimentation) and nutrient outputs (in harvested products, crop residue removals, leaching, gaseous losses, surface runoff and erosion (Stoorvogel and Smaling, 1990).

Sanchez (2002) noted that inadequate plant nutrients are one of the principal causes for low agricultural productivity and food insecurity in Africa. In Sub-Saharan Africa, smallholder farmers have been experiencing declining agricultural productivity mostly due to soil fertility depletion, which leads to food insecurity. Food production has therefore depended on nutrient mining approach since very small amounts of nutrients are returned through fertilizer application (Ofori and Fianu, 1996). The impacts of smallholder-induced nutrient depletion are expressed in the form of continued declines in crop yields, which can be abrupt or gradual depending on soil type (Bekunda *et al.*, 2010). Shisanya *et al.* (2009) added that low and declining soil fertility arises from continuous cultivation where soil replenishment activities are too stumpy to mitigate soil nutrient mining process and soil fertility is not restored by new inputs. In East Africa, intensively cultivated highlands lose an estimated 36, 5, and 25 kg NPK ha^{-1} yr^{-1} respectively, while croplands in the Sahel decline by 10, 2, and 8 kg NPK ha^{-1}respectively (Bekunda *et al.*, 2010). The decline in soil fertility is the most imperative limitation to crop production in Sub-Saharan Africa, where most agro-ecosystems remove more nutrients. Sanchez and Jama (2002) noted that soil nutrient mining was a fundamental biophysical root cause for declining food security in the smallholder farms. In Ghana, there is a negative nutrient balance of approximately 27 kg N/ha, 4 kg P/ha and 21 kg K/ha annually (FAO, 2004). Rhodes (1995) estimated the rates of total crop uptake in Ghana at 428,700 t of N, 73,100 t of P and 414,900 t of K over 10 years. MoFA (1998) noted that the production of the main food crops in Ghana removes almost 70,000 t of N and 25,000 t of P_2O_5 from the soil annually. The use of fertilizer N, P plus K has also been estimated to be 27 % of the quantity of nutrients removed by the grain/tuber food crops in Ghana (Rhodes, 1995). He also observed that as much as 44 % of N, 42 % of P and 56 % of K taken up were present in crop residues.

The use of crop residues as sources of nutrients and soil organic matter amendment has long been a major component of many farming systems in Africa. In Ghana, however, the use of plant residues is low. Presently, most of the crop residues are removed for uses with higher economic value such as animal feed, fuel and building materials (Bationo *et al.*, 1993). Baanante *et al.* (1992) noted that as much as 70 % of crop residue produced by farmers in the Ashanti region of Ghana served no useful agricultural purpose.

2.7 Soil Fertility Management

Soil fertility points to the fact that soil at a particular area or farm site is able to support plant growth and development and yield well at a scrupulous time. Soil fertility is very crucial to crop production. However, soil fertility is declining at a very fast rate in the Guinea savannah zone soils. Declining soil fertility in this zone can be attributed to increasing population growth (pressures) and high intensive farming, which has led to overuse of the soil without replenishment. Vanlauwe and Giller (2006) reported that increasing agricultural productivity is hindered by the high decline in soil fertility in the Sub-Saharan Africa countries. The traditional methods used in soil fertility restoration and sustainability of agricultural growth have become ineffective and seems to disappear with time (Ajayi *et al*., 2007).

Earlier, people relied on natural soil fertility to produce crops and commercial production was not practised. As populations' growth increased and commercial production began, natural soil-nutrient capital gradually depleted and farmers are forced to sufficiently compensate losses by returning nutrients to the soil via fertilizers especially mineral fertilizers. Small scale farmers are poor, lack technical know-how and cannot therefore afford the recommended rates of the in-organic fertilizers to increase their crop yields and, just purchase the quantities that they can afford which are far below the recommended rates for improvement of yield (Kombiok *et al*., 2012). The problem is compounded because farmers are unable to purchase mineral fertilizers (relatively high cost) and therefore rely mostly on natural soil fertility which is low and declining. Increasing pressures on agriculture has resulted in much higher nutrients outflows and the subsequent breakdown of many traditional soil fertility maintenance strategies. These traditional fertility maintenance strategies such as fallowing, intercropping, crop rotation, mixed-cropping, mixed-farming (crop vrs animal production) and opening new lands have not been replaced by an effective fertilizer supply (Sanders *et al*., 1996).

The bulk of the food in Africa is produced on smallholder farms (Gladwin *et al.*, 1997). On smallholder farms, soil fertility decline has been recognised as one of the major biophysical constraints affecting agriculture particularly nitrogen and phosphorus deficiencies (Mokwunye *et al*., 1996). The use of mineral fertilizers is the most effective and convenient way to improve soil fertility. However, mineral fertilizer use in Ghana has dropped due mainly to the high cost of mineral fertilizers (Gerner *et al*., 1995). The situation is critical especially when the poor farmer has to bear the full cost of production owing to the removal of subsidies on mineral fertilizers. The major effect of soil fertility decline in Ghana is the observed reduced food production leading to food insecurity, hunger and poverty.

In order to sustain soil and crop productivity, it is necessary to explore alternative soil fertility replenishment strategies, which are effective and affordable to farmers and environmentally sound, especially to the smallholder farmer and the ecosystem. Organic nutrient management based on biodegradable material is one such alternative that can help replenish soil fertility. Among the most promising organically based soil nutrient management practices include use of animal manure, incorporation of crop residues and improved legume fallows (Place *et al.*, 2003).

2.8 Soil Organic Matter

Soil organic matter is the organic component of soil, consisting of three primary parts including small (fresh) plant residues and small living soil organisms, decomposing (active) organic matter and stable organic matter (humus). Soil organic matter serves as a reservoir of nutrients for crops, provides soil aggregation, increases nutrient exchange, retains moisture, reduces compaction and surface crusting, and increases water infiltration into soil. Components vary in proportion and have many intermediate stages.

Soil organic matter can be divided into 2 major groups: 1. Particulate organic matter (active fraction) and 2. Humus

1. Particulate organic matter (active fraction): Many compounds (sugars, starches, certain proteins) in this soil organic matter group are quickly and easily decomposed by fungi and bacteria, so the carbon and energy they provide is readily available. Most of the microbes in the soil have the enzymes needed to decompose these simple compounds. Particulate organic matter in depleted soils can be increased by planting legumes (clovers, alfalfa, soybeans, etc.) also called "green manuring".
2. Humus (stabilized organic matter): is resistant to biological degradation because it is either physically (e.g., lignins contained in woody biomass) or chemically (e.g., humic acids) less accessible to microbial activity. Humus is a critical component for the long term sustainability of a soils' ability to provide plant nutrients especially nitrogen.

Horwath (2005) recognized that soil organic matter plays an important role in soil biological (provision of substrate and nutrients for microbes), chemical (buffering and pH changes) and physical (stabilization of soil structure) properties. These properties along with soil organic carbon, nitrogen and phosphorus are crucial indicators for the health and quality of soil.

The management of soil organic matter is critical to maintaining a productive organic farming system. Nutrient management in organic agriculture is an important consideration that impacts both crop yield and quality and also dependent primarily on the organic amendments and biological nitrogen fixation (Horwath, 2005). The utmost challenge to organic farmers is how to synchronize nutrient availability from diverse fertility sources to meet the demand of their crops. The challenge can be remedied through organic matter management (using organic materials as soil amendments), but requires an understanding of factors affecting soil organic matter maintenance and decomposition of the organic materials. The successful management of soil fertility can produce high crop yields and quality equivalent to conventional agriculture.

2.8.1 Inherent Factors Affecting Soil Organic Matter

Inherent factors affecting soil organic matter such as climate and soil texture cannot be changed. Climatic conditions such as rainfall, temperature, moisture and soil aeration (oxygen levels) affect the rate of organic matter decomposition (Snapp and Grandy, 2011). Organic matter decomposes faster in warm humid climates and slower in cool dry climates. Organic matter also decomposes faster when soil is well aerated (higher oxygen levels) and much slower on saturated wet soils.

Soils formed under grass (prairie) vegetation usually have organic matter levels at least twice as high as those formed under forests because organic material is added to topsoil from both top growth and roots that die back every year. Soils formed under forests usually have comparably low organic-matter levels because of two main factors;

1. Trees produce a much smaller root mass per acre than grass plants and

2. Trees do not die back annually and decompose every year. Instead, much of the organic material in a forest is tied up in the tree's wood rather than being returned to the soil annually.

2.8.2 Soil Organic Matter in Relation with Soil Functions

Depending on site conditions, soil management and climatic conditions mineralization rate and soil organic matter loss can increase dramatically, if temperature, aeration and moisture conditions are favourable. Key soil functions of soil organic matter include:

- Nutrient Supply: Upon decomposition, nutrients are released in a plant-available form while maintaining current levels.
- Water-Holding Capacity: Organic matter behaves somewhat like a sponge. It has the ability to absorb and hold up to 90% of its weight in water. Another great advantage of organic matter is that, it releases nearly all of the water it holds for use by plants.
- Soil Aggregation: Organic matter improves soil aggregation, which improves soil structure. Water infiltration through the soil then improves, which improves soil's ability to take up and hold water.
- Erosion Prevention: Because of increased water infiltration and stable soil aggregates erosion is reduced with increased organic matter (Snapp and Grandy, 2011).

2.8.3 Soil Organic Matter Nutrient Sources

The formation of soil organic matter promotes the capture of nutrients into its structure, especially the important nutrients nitrogen, phosphorus and sulphur. Soil organic matter composes mainly of carbon (55%), 5 to 6 % nitrogen and 1% of both phosphorus and sulphur. Soil organic matter contains carbon, which is an energy source for micro-organisms similar to fresh plant residue input (Horwath, 2005). The decomposition of soil organic matter releases nutrients for plant uptake. The amount of nitrogen mineralized can meet the entire nitrogen needs of a crop; however the timing of mineralization often does not coincide with crop needs. Lack of synchrony between mineralization of soil nitrogen to crop need is a major challenge in organic systems that rely on nutrients from the turnover of soil organic matter and the decomposition of organic inputs such as cover crops, compost, crop residues and animal manures.

The activities of decomposers are influenced by the quality of soil carbon and its interaction with minerals within soil organic matter fractions, which affects the availability of nutrients. Horwath *et al.* (2002) noted that high carbon content of soil organic matter fractions often lead to microbial immobilization of nutrients through the production of biomass that requires additional nitrogen for growth. The same authors added that the requirement for additional nitrogen to decompose poorer quality crop or cover crop residue directly competes for nutrients that crops could utilize. Indirect positive effects of soil organic matter includes soil physical property improvements that promote healthy plant growth allowing plants to capture more nutrients and facilitates water mediated nutrient movement to the roots.

2.8.4 Management of Soil Organic Matter and Nutrient Sources

Soil organic matter management requires active inputs like organic amendments and mineral fertilizers to supplement loss through decomposer activities and uptake of nutrients by crop. Soil organic matter generally increases where biomass production is higher and organic material additions occur. Plant residue with a low carbon to nitrogen ratio (high nitrogen content) decomposes more quickly than those with a high carbon to nitrogen ratio. Excessive tillage destroys soil aggregates increasing the rate of soil organic matter decomposition. Stable soil aggregates increase active organic matter and protect stable organic matter from rapid microbial decomposition. Measures that increase soil moisture, soil temperature and optimal aeration accelerate soil organic matter decomposition. Some key management measures that can increase soil organic matter are:

- Use of cropping systems that incorporate continuous no-till, cover crops, solid manure or other organic materials, diverse rotations with high residue crops and perennial legumes or grass used in rotation.
- Reducing or eliminating tillage that causes a flush of microbial action that speeds up organic matter decomposition and increases erosion.
- Reduction of soil erosion using apt measures. Most of the soil organic matter is found in the topsoil. When soil erodes, organic matter goes with it.
- Soil-test and fertilize properly. Proper fertilization encourages growth of plants, which increases root and top growth. Increased root growth can help build and maintain soil organic matter.

Sustainability of soil nutrient calls for measures that combat the loss of nutrients. These include: application of modest rates of the appropriate fertilizer, complying with recommendations that are specific to both crop and agro-ecological zones, properly timing or split application of mineral fertilizers to combat leaching; adopting more nitrogen-fixing species in cropping systems, leaving residues as mulch or ploughing them into the soil, and appropriate tillage and soil conservation measures to reduce soil erosion (Smaling *et al.*, 1992).

Organic systems rely almost exclusively on a mineralizable pool of nutrients from amendments and soil organic matter. The use of organic materials; cover crops (both leguminous and cereal), composts and animal manure are traditional ways to maintain soil organic matter and nutrients in organic systems.

2.9 Organic Manures/Materials

Organic manure comprises of cattle dung, excreta of small ruminants, poultry manure, rural and urban composts and crop residues and green manures. Organic manures vary widely in the amount of plant nutrients that they contain. Some are more nutrient concentrated than others. Compost is one of the less concentrated organic manures, but is extremely valuable in adding extra body to soils especially the sandy ones.

Soil chemical substances are taken up by plant roots in dilute solution. Organic manures are insoluble complex substances and must be broken down or decomposed before being taken up by plants' roots. Organic materials that breakdown or decompose more rapidly are available to the plant earlier than those which decay slowly. Decomposition rate of organic materials in the soil is a function of temperature. The higher the temperature, the more rapidly the decomposition and the nutrients are made available to the roots of crops and vice versa. A large amount of organic manure applied decomposes faster before the crop can use it. Hence, smaller organic materials applications are more advantageous than larger applications applied less frequently. Though the nutrient content of organic matter is low and variable, organic manure is very valuable because it improves soil condition generally.

Integrated Soil Fertility Management provides the ideal environmental conditions for crop production, as the organic manure or organic matter improves soil properties, mineral of chemical fertilizers supply the plant nutrients needed (FAO/NSPFS, 2002). Nwaiwu *et al.*, (2010) noted that organic manure used alone or in combination with inorganic fertilizer ensures increment in growth and yield of food crops, effective weed control, 50% reduction in expenditure on fertilizer, 40% topsoil retention capacity and control of soil erosion and salinity. Organic materials or manures including farmyard manure, crop residues, cattle dung, manure of other small ruminants and poultry manure may be used for the crop production as a substitute of the chemical fertilizers.

2.9.1 Cover Crops

Cover cropping has been used to enhance soil fertility and soil tilth prior to the invention of chemical fertilizers. The use of leguminous cover crops is an excellent way to increase the soil quality through the addition of organic matter and nitrogen. Mixtures of legume and cereal cover crops have been shown to be very effective at adding and preventing loss of residual nitrogen. Horwath *et al.* (2002) highlighted that it takes up to 3 years of continuous cover cropping to enjoy the benefit of sustained nitrogen availability from organic inputs. As soil organic matter builds up from the cover crop additions, equilibrium between carbon inputs and nitrogen availability occurs overcoming the initial immobilization phase often seen when converting solely to organic fertilizer amendments (Doane *et al.*, 2003).

Cover crops can bio-accumulate significant amounts of phosphorus, potassium and a range of micronutrients in organic form increasing their availability to crops in space and time. Cover crop decomposition leads to the mineralization of nutrients depending on the quality or carbon content of cover crop. Cereal cover crops should be incorporated before seed formation starts, a period when most of their nitrogen is in foliar tissue providing a low carbon to nitrogen ratio. Nitrogen recovery rates in crops following legume cover crops range from 10 to over 50% of the cover crop nitrogen (Hadas *et al*., 2002). Cover crop nitrogen recovery in crops is dependent on environmental factors (e.g. temperature, moisture etc), edaphic factors (soil conditions), type of management (e.g. shredding, mixing, soil incorporation) and cover crop residue quality (e.g. carbon: nitrogen ratio, cellulose, lignin content).

Drinkwater *et al.* (1998) showed that high nitrogen cover crops used in diverse crop rotations increased soil organic matter and the supply of available soil nitrogen. The conception of mixing residues with varying carbon to nitrogen ratios can be applied to a variety of organic amendments and cropping systems.

2.9.2 Animal Manure

Animal manure application is an important tool for organic agriculture, which can result in an increase in soil organic matter levels and soil organic matter mineralization potential. Animal manures contain a significant supply of ammonium and nitrate that are readily available to crops. The quality of animal manure (composted, fresh or aged) has an immense influence on its ability to supply nutrients. Long-term application of manures can significantly improve soil organic matter levels. Poultry manure can improve soil fertility by adding major and essential nutrients as well as soil organic matter which improves moisture and nutrient retention. Horwath *et al.* (2002) observed that the biannual application of about 10 t/ha of composted poultry manure for 10 years increased soil organic matter by 8.6 t/ha (0-30 cm) compared to a conventionally managed system. The degree to which animal manure applications affect soil organic matter levels is highly variable and depends on the quality and amount of the manure.

Animal manures are generally more resistant to decomposition than plant residues since they are somewhat partially decomposed. Therefore, timing and method of animal manure application is crucial to both soil organic matter maintenance and nutrient availability. Animal manure application should be done during periods of active decomposer activity and plant uptake. Applications during periods of slow crop growth can result in significant amount of nutrients lost to leaching, erosion and gaseous nitrogen losses to the atmosphere.

2.9.3 Compost

The nutrient content of composts varies considerably depending on type of raw materials used, method of composting and maturity. Nutrient mineralization rates from compost can vary by orders of magnitude. Composted manure releases nitrogen at a considerably slower rate than unprocessed manure (Hadas *et al*., 1996). Churchill *et al.* (1996) concluded that the crucial raison d'être for reduced nutrient availability in composts is the higher degree of decomposition leading to the production of humic substances resulting in a slower release of nutrients especially nitrogen.

Increase in stable soil organic matter and favourable soil properties can be more effectively accomplished with compost than with fresh manure. However, the amount of organic matter applied is more important than the type of organic amendments used in the long term (Horwath *et al*., 2002). Joyce *et al.* (2002) observed that organic management with composts improved porosity and water retention. Horwath *et al.* (2002) observed that biological soil quality indicators such as biomass carbon and nitrogen improved with compost applications.

2.9.4 Rice Husk and Rice Straw

Doran and Smith (1987) highlighted that crop residue management practice can influence agricultural sustainability by altering the organic matter status, physical and chemical properties of the soil for better microbial activity and diversity. Saha *et al*. (2007) stated that incorporation of crop residue, cow dung increased the organic carbon and nutrient content of soils and increases crop yields. Vanlauwe *et al*. (2004) postulated that combining plant biomass and mineral fertilizers may provide an intermediate solution to soil depletion allowing the most efficient use of scarce resources. Palm *et al*. (1997) concluded that the outcome of the combination may depend on the quality of the plant biomass.

Comparison between rice straw and rice husk shows that both materials have relatively similar properties except in organic carbon content (Masulili *et al*., 2010); the organic carbon content of rice husk is relatively higher than rice straw.

Saha *et al*. (2007) concluded that rice straw incorporation can increase soil organic matter content and Kavimandan *et al*. (1987) mentioned that rice straw increased crop yield in rice-rice and rice-wheat systems.

Sitio *et al*. (2007) used rice husk ash for the improvement of rice growth and yield in the peat soil of Sumatra. The ability of rice husk and rice husk ash to remove heavy metals from the system has also been shown by Mahvi *et al*. (2005). They added that the main limitation in using such organic matter is the easiness of these materials to be decomposed, and therefore its application must be done repeatedly from year to year.

The nutrient recycling of rice residue and other organic materials in a rice cropping system is increasing in accordance with the current renewed interest on sustainable soil fertility and crop productivity. Rice straw incorporated into the soil after the rice harvest combined with the application of cattle manure significantly increased the grain yield over the yields from incorporation of the rice straw alone (Polthanee *et al*., 2011) and provided a higher supply of potassium, but a lower supply of nitrogen and phosphorus than other organic materials (Javier *et al*., 2002). At crop maturity, the rice straw has about 40% of nitrogen, 30-35% of phosphorus and 80-85% of potassium (Dobermann and Fairhurst, 2002). Mandal *et al.* (2004) added that rice straw improves the soil's physical, chemical and biological properties. Incorporation of rice straw into the soil combined with the application of cattle manure, rice crop received additional nitrogen, phosphorus and potassium from the cattle manure (Polthanee *et al*., 2011). Pham *et al.* (2001) reported that rice straw can be composted rapidly within 45 days. Incorporating rice straw into the soil returns most of the nutrients and helps to conserve soil nutrient reserves in the long term. Short term effects on grain yield are often small compared with straw removal or burning, but long term benefits are significant.

2.9.5 Biochar

Biochar, a stable form of carbon (C), is produced from pyrolysis of biological materials (Shenbagavalli and Mahimairaja, 2012) at temperatures between 300 °C–1000 °C (Glaser *et al*., 2001). A variety of types of biomass can be used on a commercial scale for biochar production successfully. These biomasses may include agricultural and forestry byproducts (such as straw, nut shells, rice hulls, wood chips, tree bark, and switch grass), industrial by-products (such as bagasse from the sugarcane industry, paper sludge, and pulp), animal wastes (such as chicken litter, dairy and swine manure) and sewage sludge. It is attracting growing interest because of its' potential to improve soil nutrients statue, increase crop yield and sequester carbon in the soil. Shenbagavalli and Mahimairaja (2012) noted that the chemical structure of the charcoal (biochar) is characterized with poly-condensed aromatic groups, providing prolonged biological and chemical stability that sustains the fight against microbial degradation. It provides after partial oxidation the highest nutrients retention. Biochar contains hydrocarbon aromatic polycyclic carbon with functional groups (Krull *et al*., 2009; Chintala *et al*., 2013).

Charred biomass residues application to soils is one of the most promising strategies to sustainably sequester atmospheric carbon dioxide in agricultural soils (Sohi *et al*., 2010). Engineering biochars to have specific properties can increase its ability to serve as a soil amendment and/or as a low-cost sorbent for organic and inorganic pollutants (Novak *et al*., 2009). The increase in crop yield with biochar application has been reported for crops such as cowpea (Yamato *et al*., 2006), soybean (Tagoe *et al*., 2008), maize (Yamato *et al*., 2006 and Rodríguez *et al*., 2009) and upland rice (Asai *et al*., 2009). Haefele *et al*., (2008) discussed the possibility of biochar applications for rice-based cropping systems. Reichenauer *et al*., (2009) concluded that the application of 2 t/ha of rice-husk-charcoal increased the grain yield from less than 4t/ha for the control treatment to more than 5t/ha for the biochar treatment. Spokas *et al*. (2012) highlighted that application of biochar can lead to positive results in agricultural production.

However, there have been some reports of no crop yield benefits (Schnell *et al*., 2012) or even negative yield responses (Lentz and Ippolito, 2012). Vaccari *et al*. (2011) observed that high rates of biochar application have no negative effects on growth, but rather stimulated wheat grain production greater than 25%. Results from semi-arid soils in Australia have shown positive response to biochar in combination with inorganic fertilizer in pot trials (Chan *et al*., 2007), and in Indonesia maize and peanut yields were enhanced where bark charcoal was applied in combination with nitrogen fertilizer in the field (Yamato *et al*., 2006). Biochar and inorganic fertilizer combination increased okra fresh fruit yield compared to sole inorganic fertilizer application (Yeboah *et al*., 2013). Widowati and Asnah (2014) concluded that sole biochar application increased maize production by 14% compared sole application of KCl fertilizer In contrast, dual application of biochar and 75% lower dosage of KCl fertilizer application increased maize production by 29%. The same authors noted that application of biochar and KCl fertilizer at the rate of 50 kg/ha resulted in the highest relative agronomic effectiveness (137%) and K fertilizer efficiency (18%). Baronti *et al.* (2010) stressed that highest dry matter increase (120%) was obtained on biochar application at the rate of 60 Mg/ha, consequently any higher rate would decreases biomass.

Yeboah *et al.* (2013) observed that biochar amendments increased soil moisture storage by 14% relative to sole inorganic fertilizer applications. The same authors added that biochar plus inorganic fertilizer relative to sole inorganic fertilizer increased soil available nitrate concentration by 85% at 0-15 cm soil depth but decreased soil ammonium-nitrogen by 71% and concluded that biochar when combined with inorganic fertilizer has tremendous potential to address food insecurity through soil moisture storage and soil nitrogen availability. Widowati and Asnah (2014) reported that biochar application increased the availability of nutrients by 69-89% for K^{+}, 61-70% for Ca^{++}, 39-53% for total nitrogen, 179-208% for phosphorus, and 14-184% for potassium.

Biochar made from rice husk grown in acid sulphate soil and other organic soil amendment applications significantly improve some properties of the acid sulphate soil of West Kalimantan, Indonesia, namely: decreasing soil bulk density, soil strength, exchangeable aluminium, and soluble iron, and increasing soil pH, soil organic matter, total phosphorus, cation exchangeable capacity, exchangeable potassium, and exchangeable calcium (Masulili *et al.*, 2010). Sukartono *et al.* (2011) reported that biochar application improved soil fertility status especially soil organic carbon, cation exchange capacity, available phosphorus, exchangeable potassium, calcium and magnesium and increased nutrient uptake and maize yield. Soil organic carbon increased from about 0.9% (untreated soil) to about 1.20% (biochar). The same authors added that soils treated with biochar had consistently higher organic carbon contents, which also remained more stable, compared to the soils treated with chemical fertilizer implying the higher potential of biochar for soil carbon sequestration. Biochar has surface area and porosity which are significant in improving water holding capacity, adsorption and nutrient retention (Sohi *et al*., 2010; Chintala *et al*., 2013). Amonette and Joseph (2009) indicated that biochar can affect soil structure, texture, porosity, particle size distribution and density, hence can improve aeration, water storage capacity and microbes and nutrient availability in the root zone of plants. Application of biochar leads to changes in pH, electrical conductivity (EC), cation exchange capacity (CEC) and nutrient availability (Liang *et al*., 2006; Gundale and DeLuca, 2007; Warnock *et al*., 2007). Biochar reduced nitrogen leaching and improve nitrogen use efficiency (Steiner *et al*., 2008; Widowati *et al*., 2012 and Chintala *et al*., 2013).

2.10 Timing of Application of Organic Materials/Manures

Timing of application is a fundamental constituent in maximizing nitrogen use efficiency in organic manures. Thomsen (2005) concluded that organic manure management is more complicated than mineral fertilizers primarily because manure and other organic fertilizers are affected by handling during storage and application as well as incorporation timing and distribution. He added that autumn applications of organic manures increased nitrogen loss through the soil system, in comparison with later applications that lead to increased crop utilization of nitrogen. Asim *et al.* (2013) noted that the optimum planting date of crops and/or its validation is essential to sustain productivity under climate change. A significant change on the growth and yield of maize has been already observed due to climate changes

(Binder *et al*., 2008; Meza *et al*., 2008). Optimum maize planting date is important with respect to regional climate change (Laux *et al*., 2010).

Nitrogen is typically the nutrient of most concern because it has a strong influence on cereal crop yields (Havlin *et al*., 2005). Nitrogen is taken up by plants in the form of ammonium ($NH4^{+}$), a result of mineralization and $NO3^{-}$, a result of nitrification. In organic manure about 50 to 75% of total nitrogen is organic (R-NH2) and needs to undergo mineralization before it becomes available for plants and the remaining 25 to 50% is $NH4^{+}$ is highly susceptible to volatilization (Havlin *et al*., 2005). Mineralization and nitrogen recycling begin as soon as the manure is incorporated into the soil. Havlin *et al*. (2005) added that mineralization rate varies among nitrogen sources, but the rate is highest at application and decreases with time. Nutrients contained in organic manures are released more slowly and stored for a time in the soil, thereby ensuring a long residual effect (Sharma and Mittra, 1991), supporting better root development and higher crop yield (Abou El-Magd *et al*., 2005); activates soil microbial biomass thereby increasing soil fertility (Belay *et al*., 2001).

2.11 Advantages and Concerns of Organic Matter Management

The accumulation of soil organic matter under organic management can lead to enhanced soil fertility through the sequestration of plant nutrients especially nitrogen. Overall, managing for increased soil organic matter greatly enhances the ability of soils to cycle nutrients sustainably provides habitat for more soil organisms, increases microbial diversity and creates a favourable environment for plants to exist. The application of composts and manures to soils on a consistent basis may impact soil fertility in numerous ways.

Organic matter is the source of 90-95% of the nitrogen in unfertilized soils. Organic matter is the major source of both available phosphorus and available sulphur when soil humus is present in appreciable amounts. Organic matter supplies directly or indirectly through microbial action the major soil aggregate-forming cements particularly the long sugar chains called polysaccharides. Organic matter contributes to the cation exchange capacity. The large available surfaces of humus have many cation exchange sites that absorb nutrients for eventual plant use and temporarily absorb heavy metal pollutants (lead, cadmium, and the like), which are usually derived from applied waste waters. Adsorption of these probably helps clean contaminated water. Organic matter commonly increases water content at field capacity, increases available water content in sandy soils and increases both air and water flow rates through fine textured soil. Organic matter is a carbon supply for many microbes that perform other beneficial functions in soil.

When left on top of soil as mulch, organic matter reduces erosion, shades the soil and keeps the soil cooler in very hot weather and warmer in winter.

Humus buffers the soil against a rapid change in acidity, alkalinity and salinity, and damage by pesticides and toxic heavy metals.

Clark *et al.*, (1998) postulated that the use of animal manure and compost as a sole source of available nutrients can result in nutrient overloading of the soil. Excess phosphorus levels are created frequently by basing manure and compost application rates solely on the crop nitrogen need. Potential consequences of overloading the soil with nutrients include leaching of nitrate (Poudel *et al.*, 2001) and accumulation of phosphorus in the soil (Gartley and Sims, 1994).

2.12 Inorganic Fertilizers in Soil fertility Management

The most common of the materials used as soil fertility enhancing substances are the organic and inorganic fertilizers. However, inorganic fertilizer use in the Sub-Saharan Africa region is very low compared with the world average, in spite of many African farmers being aware of the beneficial contribution of mineral fertilizers to crop production. Average rate of inorganic fertilizer use in Sub-Saharan Africa (excluding South Africa) is 10 kg ha^{-1} as compared to 87 kg ha^{-1} for the developed countries (Bationo *et al.*, 2006). Sub-Saharan Africa accounts for less than 1.8% of the global fertilizer use and less than 0.1% of global fertilizer production (FAO, 2008). Vlek (1990) attributed the laxity to farmers' lack of confidence in the economic returns of fertilizing food crops and inadequate knowledge on which kinds and rates of fertilizers are recommended for their specific crops, soils and agro-climatic conditions. Heisey and Mwangi (1996) added that high price of imported fertilizers at farm gate and delays in delivery due to poor transportation and road network have forced smallholder farmers often to apply smaller rates of inorganic fertilizer late in the growing season, which causes poor crop yields.

Adeniyi and Ojeniyi (2003) noted that inorganic fertilizer usage was an imperative resource for supplying soils with the necessary nutrients for optimum crop production, however Ojeniyi (2000) distinguished that continuous usage have negative effects on the environment. Nitrate leaching, groundwater pollution, degradation of soil structure, decreased surface water infiltration (Pondel *et al.*, 2001) rapid degradation of soil physical, chemical and biological qualities (Ojeniyi and Adejobi, 2000) are associated with the use of mineral fertilizer. Enhanced soil fertility and improved environmental quality are both important goals of today's agriculture. Therefore, there is a global move towards developing an agricultural production system which involves the more efficient utilization of inputs and the reduction of waste products (Ralph, 1996).

Kombiok *et al.* (2012) noted that the recommended rates of inorganic fertilizers for the production of cereals especially maize in Ghana are the basal application of compound fertilizer (NPK 15-15-15) at planting or two weeks after planting of two (2) fifty kilograms (50 kg) bags per acre. This should be followed by the application of either sulphate of Ammonia or urea at one (1) fifty kilogram bag (50 kg bag) or twenty-five kilogram bag (25 kg bag) per acre respectively just before the tasselling of maize.

In Sub-Saharan Africa, greater use of mineral fertilizers is crucial to increasing food production and slowing the rate of environmental degradation. Regional growth rates in fertilizer consumption have never been particularly high, in part because the real price of fertilizer is higher in Africa than in many other developing regions (Heisey and Mwangi, 1996). The same authors noted that during the period of declining growth in consumption, fertilizer use on cereals particularly maize, has become relatively more important than use on cash crops. Therefore, strategies for increasing mineral fertilizer use should direct more attention to maize and other important staples.

2.13 Integrated Soil Fertility Management

The broad aim of Integrated Soil Fertility Management (ISFM) is to utilise available organic and inorganic sources of nutrients in a judicious and efficient manner. Scoones and Toulmin (1998) postulated that continuous nutrient diminution and low soil fertility has not only led to the development of integrated soil fertility management technologies that offer potential for improving soil fertility in Africa, but concurrently triggered far-reaching studies on nutrient balance in various African farming systems. Protection and improvement of the soil makes economic and social sense (Bekunda *et al.*, 2010).

Based on the evaluation of soil quality indicators, Dutta *et al.* (2003) reported that the use of organic fertilisers together with chemical fertilisers compared to the addition of organic fertilisers alone had a higher positive effect on microbial biomass and hence soil health. Sutanto *et al.* (1993) in their studies on acid soils for sustainable food crop production noted that farmyard manure and mineral fertiliser produced excellent responses. Boateng and Oppong (1995) studied the effect of farmyard manure and method of land clearing on soil properties on maize yield and reported that plots treated with poultry manure and NPK (20-20-0) gave the best yield results. Several researchers have also established the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only nitrogen, phosphorus and potassium fertilizers for a few years, without any micronutrient or organic fertilizer. Quansah (2000) postulated that integrated plant nutrition can increased crop yields more than either used alone. Soil fertility replenishment for sustaining crop productivity should use all possible sources of plant nutrients in an integrated manner (FAO, 1993). Bokhtiar and Sakurai (2005) confirmed that application of organic manure in combination with chemical fertilizer increased absorption of nitrogen, phosphorus and potassium in sugarcane leaf tissue in the plant and ratoon crop, compared to chemical fertilizer alone. Prasithikhet *et al.* (1993) recommended that a low rate of compost manure should be used with mineral fertilizer over a long period in order to promote high rice yields and good soil fertility. Quansah *et al.* (1998) observed an increased crop yields when a jumble of organic and mineral fertilizers was applied compared with sole application of organic or mineral fertilizer.

Emerging evidence indicates that integrated soil fertility management involving the judicious use of combinations of organic and inorganic resources is a feasible approach to overcome soil fertility constraints (Abedi *et al.*, 2010). Mishmash of organic/inorganic fertilization both enhanced carbon storage in soils and reduced emissions from nitrogen fertilizer use, while contributing to high crop productivity in agriculture (Pan *et al.*, 2009).

Addition of organic materials of various origins to soil has been one of the most common practices to improve soil physical properties (Celik *et al.*, 2004). The use of NPK and farmyard manure increased soil organic matter, total nitrogen, Olsen phosphorus and ammonium acetate exchangeable potassium by 47%, 31%, 13% and 73%, respectively (Bhattacharyya *et al.*, 2008). Mando *et al.* (2005) found that soil organic matter and crop performance was better maintained using organic material with a low carbon to nitrogen ratio (manure) than with a high carbon to nitrogen ratio (straw). In addition, Zhao *et al.* (2009) reported that farmyard manure combined with chemical fertilizer management resulted in a higher increase in maize yield, soil organic matter, available nitrogen and available phosphorus compared with those found under straw manure combined with chemical fertilizer management.

CHAPTER 3 : MATERIALS AND METHODOLOGY

3.1 Site Description

A pot and a field experiments were carried out in 2014 cropping season at the University for Development Studies, Nyankpala campus to determine the optimum time for planting after incorporation of the organic materials and the appropriate organic material(s) to enhance maize grain yield and yield components in Northern Ghana. The pot trial was conducted in a glasshouse and the field was carried out on the farm for the future. The experiments were conducted at Nyankpala, near Tamale, in the Guinea savannah zone of Ghana, West Africa. Nyankpala is located at latitude 9°25' 14'N, longitude 0° 58' 42'W and at an altitude 183 m above sea level (NAES, 1992). The green house is located at geographical positioning system of latitude 09°24'44.4"N and longitude 00°58'49.7"W.

The area experiences unimodal rainfall with an annual mean rainfall of 1000 to 1022mm. The temperature distribution is fairly uniform with mean monthly minimum of 21.9°C and a maximum of 34.1°C. It has a minimum relative humidity of 46% and maximum of 76.8%.

The soil of the study site is a typical upland soil, developed from iron stone gravel and ferruginized ironstone brash (Adu, 1957). The soil is classified as a Haplic Lixisol (FAO/UNESCO, 1997) and locally referred to as the Tingoli series (Serno and van de Weg, 1985). The pot experiment was conducted from April to June, 2014 and the field experiment from July to November, 2014.

3.2 Pot Trial

3.3 Experimental Design and Treatments

The experiment was a 4×5 factorial experiment consisting of 4 Organic materials (rice straw, rice husk, biochar and groundnut shells and 5 days after incorporation of organic materials (7, 14, 21, 28 and 35 days). There were twenty (20) treatments in every replication. The experiment was laid out in a Randomized Complete Block Design due to heterogeneity of conditions in the glass house. This was done to reduce experimental errors by eliminating the contributions of known sources of variations in the experiment. The experiment was replicated three (3) times. There were sixty (60) experimental pots in totality. The treatments were as in Table 1 below;

Table 1: Pot Trial Treatments

Code	Treatments
1	Rice straw + 7 Days After Incorporation
2	Rice straw + 14 Days After Incorporation
3	Rice straw + 21 Days After Incorporation
4	Rice straw + 28 Days After Incorporation
5	Rice straw + 35 Days After Incorporation
6	Rice husk + 7 Days After Incorporation
7	Rice husk + 14 Days After Incorporation
8	Rice husk + 21 Days After Incorporation
9	Rice husk + 28 Days After Incorporation
10	Rice husk + 35 Days After Incorporation
11	Biochar + 7 Days After Incorporation
12	Biochar + 14 Days After Incorporation
13	Biochar + 21 Days After Incorporation
14	Biochar + 28 Days After Incorporation
15	Biochar + 35 Days After Incorporation
16	Groundnut shells + 7 Days After Incorporation

17	Groundnut shells + 14 Days After Incorporation
18	Groundnut shells + 21 Days After Incorporation
19	Groundnut shells + 28 Days After Incorporation
20	Groundnut shells + 35 Days After Incorporation

3.4 Preparation of Soil Samples and Planting Materials

Six (6) holes were created under the plastic buckets that were used as pots and first filled with garden soil to a height of 20cm from the base of each plastic bucket. Each pot contains garden soil of the volume of 0.0629m^3. Each pot had a surface area of 0.0314m^2.

Each of the organic materials weighing 156.2g was mixed thoroughly with each soil in the various pots.

Rice straw was obtained from farmers' fields in Bontanga and Nyankpala rice fields. The rice straw was chopped into small fine pieces for easy incorporation into the pot soil. The rice husk was obtained from Savannah Agricultural Research Institute (SARI) rice mill in Nyankpala. Also, the grounded groundnut shells shall be obtained from a groundnut shelling machine in Nyankpala. The groundnut shells were grounded into small sized particles for easy incorporation. However, biochar is a product obtained from burning agricultural residues at low oxygen concentration. Therefore, the biochar was prepared by burning rice husk at low oxygen concentration.

3.5 Agronomic Practices

Hand-watering of the potted plants was done twice daily to promote the decomposition of the organic materials and the growth of the maize plants.

Four (4) maize seeds were planted at stake. The maize plants were thinned-out two weeks after planting to three plants per pot.

All weeds that appeared in the pots were removed to prevent competition with the maize plants.

3.6 Data Collection

Data was collected on the following;

- Days to emergence
- Plant height
- Leaf count and
- Total Dry matter weight

3.6.1 Days to Emergence

The number of days the maize took to emerge from the soil was monitored and recorded.

3.6.2 Plant Height

The height of the three (3) maize plants in each pot was measured at 2, 3, 4, 5 and 6 WAP. Tape measure was used to measure the heights from the base of the plant to the flag leaf and their averages recorded.

3.6.3 Leaf Count

The number of leaves for the three (3) plants in each pot was counted at 2, 3, 4, 5 and 6 weeks after planting (WAP).

3.6.4 Total Dry Matter

Three (3) plants from each pot were harvested and kept in envelops and oven dried at 105°C for 24 hours to determine the total dry matter weight. An electronic scale was used for weighing of the samples. This was done at 6 WAP.

3.7 Field Experiment

3.8 Experimental Design and Treatments

The experiment was a 4×3×3+1 factorial experiment made up of the same 4 organic materials as in the pot experiment at 2.5, 5 and 7.5 t ha^{-1} dry matter basis and 3 N-P-K fertilizer grades (0-0-0 kg NPK ha^{-1}, 45-30-30 kg NPK ha^{-1} and 90-60-60 kg NPK ha^{-1}) plus a pure control (zero organic materials and inorganic fertilizer). The experiment was laid in a Randomized Complete Block Design (RCBD) with four (4) replications. There were thirty-seven plots (treatments) in each replication with each plot measuring 5 m × 5 m making a total plot size of 25 m^2. There were 148 experimental plots in totality. A 1 m alley was left between plots within a replication and a 2 m alley between replications. The treatments were as in Table 2 below;

Table 2: Field Trial Treatments

No	Treatments
1	Control
2	2.5 t/ha Rice Straw
3	5 t/ha Rice Straw
4	7.5 t/ha Rice Straw
5	2.5 t/ha Rice Straw + 45-30-30 kg NPK/ha
6	2.5 t/ha Rice Straw + 90-60-60 kg NPK/ha
7	5 t/ha Rice Straw + 45-30-30 kg NPK/ha
8	5 t/ha Rice Straw + 90-60-60 kg NPK/ha
9	7.5 t/ha Rice Straw + 45-30-30 kg NPK/ha
10	7.5 t/ha Rice Straw + 90-60-60 kg NPK/ha
11	2.5 t/ha Rice Husk
12	5 t/ha Rice Husk
13	7.5 t/ha Rice Husk
14	2.5 t/ha Rice Husk + 45-30-30 kg NPK/ha

Table 3: Field Trial Treatments

No	Treatments
15	2.5 t/ha Rice Husk + 90-60-60 kg NPK/ha
16	5 t/ha Rice Husk + 45-30-30 kg NPK/ha
17	5 t/ha Rice Husk + 90-60-60 kg NPK/ha
18	7.5 t/ha Rice Husk + 45-30-30 kg NPK/ha
19	7.5 t/ha Rice Husk + 90-60-60 kg NPK/ha
20	2.5 t/ha Biochar
21	5 t/ha Biochar
22	7.5 t/ha Bio char
23	2.5 t/ha Biochar
24	2.5 t/ha Biochar + 90-60-60 kg NPK/ha
25	5 t/ha Biochar + 45-30-30 kg NPK/ha
26	5 t/ha Biochar + 90-60-60 kg NPK/ha
27	7.5 t/ha Biochar + 45-30-30 kg NPK/ha
28	7.5 t/ha Biochar + 90-60-60 kg NPK/ha
29	2.5 t/ha Groundnut Shells
30	5 t/ha Groundnut Shells
31	7.5 t/ha Groundnut Shells
32	2.5t/ha Groundnut Shells + 45-30-30kg NPK/ha
33	2.5 t/ha Groundnut Shells + 90-60-60 kg NPK/ha
34	5 t/ha Groundnut Shells + 45-30-30 kg NPK/ha
35	5 t/ha Groundnut Shells + 90-60-60 kg NPK/ha
36	7.5t/ha Groundnut Shells + 45-30-30 kg NPK/ha
37	7.5 t/ha Groundnut Shells + 90-60-60 kg NPK/ha

3.9 Field Practices

The experimental field was demarcated prior to experimental setup and ploughed using a tractor. The total land area was 78 m × 78 m making a total size of 1.58 acres. After laying-out, the various organic materials were then applied on their respective plots. Incorporation of organic materials and levelling were done manually using human labour. The organic materials were applied on dry a matter basis at the rates of 2.5, 5 and 7.5 t ha^{-1} 28 days before planting maize with reference to the results from the pot experiment.

The 3 N-P-K fertilizer grades (0-0-0 kg NPK ha^{-1}, 45-30-30 kg NPK ha^{-1} and 90-60-60 kg NPK ha^{-1}) were superimposed on the organic materials rates. Bounding was later done to separate plots from each other to prevent fertilizer drift.

The experiment field was left undisturbed for 28 days. Prior to planting, the experiment field was sprayed with glyphosate a non-selective herbicide to kill all weeds to avoid competition. The seeds were planted on 14th July, 2014 at a spacing of 80 cm between rows and 50 cm within rows. Two seeds were planted per hill. It was 'Wang-Data' maize hybrid that was planted. The hybrid has a maturity period of 90-95 days (3 month).

3.9.1 Fertilizer Grades Calculation

Equation 1

$$\text{Mass of fertilizer} = \frac{\text{Mass of nutrient recommended (kg)}}{\text{Analysis of fertilizer (\%)}} \quad \text{......................... Equation 1}$$

Recommended rate of fertilizer = 90-60-60 kg NPK/ha

Mineral fertilizers available were; Compound fertilizer (15-15-15 NPK) and Ammonia sulphate (21%N).

3.9.2 Organic Materials and Inorganic Fertilizer Application

The organic materials were biochar, groundnut shells, rice straw and rice husk. The rice straw was collected from farmers' fields, whiles the rice husk was obtained from the Savannah Agricultural Research Institute (SARI) rice milling site in Nyankpala. The grounded groundnut shells were also collected from a groundnut shelling site in Nyankpala. However, the biochar was obtained by subjecting rice husk to high carbon dioxide and low oxygen concentrations using a local device called 'kuntan'. The organic materials were applied on dry a matter basis at the rates of 2.5, 5 and 7.5 t ha^{-1} 28 days before planting of the maize.

Three (3) rates of inorganic fertilizer 0-0-0 kg NPK ha^{-1}, 45-30-30 kg NPK ha^{-1} and 90-60-60 kg N-P-K ha^{-1} were superimposed on the organic materials rates. The inorganic fertilizer used for the first application was nitrogen, phosphorus and potassium from the compound fertilizer NPK 15-15-15. The first application was done 14 to 21 Days After Planting (DAP) due to drought and the remaining nitrogen for top dressing was obtained from Ammonia sulphate (21%N) fertilizer and applied 42 DAP by band placement.

3.9.3 Weed Management

Prior to planting, glyphosate (non-selective) herbicide was applied to kill all weeds to avoid early competition. The first hand weeding was done 18 Days After Planting (DAP) and the second hand weeding was done 40 DAP. Third hand weeding was done after 75 DAP.

3.10 Soil Sampling and Analysis

Soil samples for determination of soil available N and P were obtained from the upper soil surface layer (0 - 15 cm) using a 5 cm diameter soil auger. The soil samples were collected prior to planting at random. Four augerings were done in every replication and the soil bulked together to get one composite sample to determine the initial soil properties (Table 4). Soil analysis was also carried out for the various treatments after harvesting. Three augerings were done for each treatment in each replication and bulked for the post-harvest soil analysis (Table 9).

Table 4: Initial Soil Analysis

								SOIL TEXTURE		
		%	%	Mg/kg	Mg/kg	Mg/kg	Mg/kg	%	%	%
SOIL	pH	OC	N	P	K	Ca	Mg	SAN	CLAY	SILT
SAMPLE	5.54	0.12	0.01	3.56	51.84	64.72	27.88	90.36	1.28	8.36

3.10.1 Methods Used to Determine Soil Physio-Chemical Properties

3.10.2 Soil pH

The pH was done in water at a ratio of 1:2.5. 10 g of the sample was taken and 25 ml of water was added stirred and left to stand for about an hour and the pH electrode after standardizing was dipped into the set up and the reading taken.

3.10.3 Organic Carbon

This was done by the Walkley and Black method, a known weight was taken into a conical flask, 10 mls of 1M of $K_2O_7Cr_2$ was added and then 20 mls of H_2SO_4 was added and left in the fume hood to cool. After cooling, 100 mls of water was added and left to cool. From there 2-3 drops of Diephenilamine indicator was added and titrated against 0.5 M of Fe_2SO_4.

3.10.4 Nitrogen

Nitrogen was done by the wet oxidation Kjedahl method; a known weight was taken into digestion tubes and digested with the Kjedahl digestion mixture to form dark brown to colourless solution at 360°C. The sample was then topped to 100 ml mark with distilled Water, an aliquot was taken and distilled through the vapodest into a conical flask containing pink boric acid, as the boric acid received the Nitrogen it turned green, it was then titrated with 0.1 M HCl from the green colour back to pink given the nitrogen titre value.

3.10.5 Phosphorus

A known weight was taken into a shaken bottle and 35 mls of Bray 1 extraction solution was added and shaken on a mechanical shaker for 8 minutes. And filtered through filter paper Whatman number 42, then the blue colour was developed and measured on the Ultra Violet Visible Spectrophotometer.

3.10.6 Potassium

A known weight was taken into a shaken bottle and 50 mls of 1 M of NH4O AC extraction solution was added and shaken on a mechanical shaker for 2 Hours. It was filtered through filter paper Whatman number 42 and measured on the Flame Photometer.

3.10.7 Texture

The texture was done by the hydrometer method, where the sand fraction was taken at 40 seconds, and the clay fraction after 5 hours using Sodium Hexametaphosphate solution (Calgon).

3.11 Harvesting

Harvesting of 40 plants per the net plot 4 m × 4 m size was carried out after the maize was fully matured on the field. The harvested maize was dried, bagged and labelled according to treatments, replications and plot numbers.

3.12 Data Collection

At 3 weeks after planting (3 WAP), 5 plants in the middle rows were randomly selected from each plot and tagged for the measurement of growth characteristics at 6 and 9 weeks after planting (WAP) as follows:

- Plant height was measured at 6 and 9 WAP
- Number of leaves per plant at 6 and 9 WAP

However, data were also taken for Days to 50% Flowering and Height of cob attachment.

After harvesting, data were collected on the following parameters;

U Cob weight

U Cob length

U Stover weight

U 100 seed weight

U Grain moisture content and

U Grain yield.

3.12.1 Plant Height

This was taken as the height of the maize plant measured to the nearest centimetre from the base to tip of the flag leaf at 6 and 9 WAP. The mean height from the 5 randomly selected plants from the middle rows was taken as the score for each plot. Measuring tape was used for the measurement.

3.12.2 Leaf Count

The number of leaves per plant was determined by counting and the data from 5 plants from the middle rows was used to compute the score for each plot at 6 and 9 WAP.

3.12.3 Days to 50% Flowering

The Days to 50 % Flowering was done by counting the number of days from planting to when half (50 %) of the maize plants on each plot produces tassels or start tasselling.

3.12.4 Height of Cob Attachment

The height of cob attachment was done by measuring from the ground to the point of cob attachment on the stalk of each of the tagged five (5) plants. This was done when the cobs were attached. A tape measure was used in taken the measurement.

3.12.5 Cob Length

Five (5) cobs from each treatment were selected and their length measured and their averages were recorded. A pair of callipers and a rule was used to the measure cob length.

3.12.6 Cob Weight

Five (5) cobs were selected from each treatment and weighed and their averages recorded. An electronic scale was used to determine the cob weight at harvest.

3.12.7 Grain yield

The total grain yield from all the 40 plants in the middle rows of each plot that were carefully harvested and threshed for full yield recovery was used to compute the grain yield in tons per hectare based on the plant population of 50,000 plants / hectare used in this study. This was estimated using the relationship below:

Equation 2: Grain Yield per Hectare

$$GYha = Y_p \times Pha \qquad \text{Equation 2}$$

Where:

GYha = Grain yield per hectare

Y_p = Average grain yield per plant

Pha = Plant population per hectare

3.12.8 100 Seed Weight

100 maize seeds in each treatment were counted and weighed using an electronic scale.

3.12.9 Stover Weight

The straws of harvested net plots were weighed after harvesting and removal of cobs.

3.13 Statistical Analysis

The data were subjected to analysis of variance using GenStat statistical package. Count data were transformed using square root transformation ($\sqrt{n} + 0.5$) to homogenize the variance before subjecting them to analysis of variance. Treatment means were separated using Least Significant Difference at 5% significant level. Results are presented in graphs and tables. Regression analysis was also done to show the linear relationship between grain yield and the yield components.

CHAPTER 4: RESULTS

4.1 Pot Trial

4.1.1 Days to Emergence

The organic materials determined (*p<0.001*) the number of days the seedlings took to emerge from the soil. Biochar and Groundnut Shells took the shortest days to emerge and were at par. Rice Straw and Rice Husk were similar and took the longest days to emerge. Figure 1 below displays the main effect of the organic materials on days to emergence.

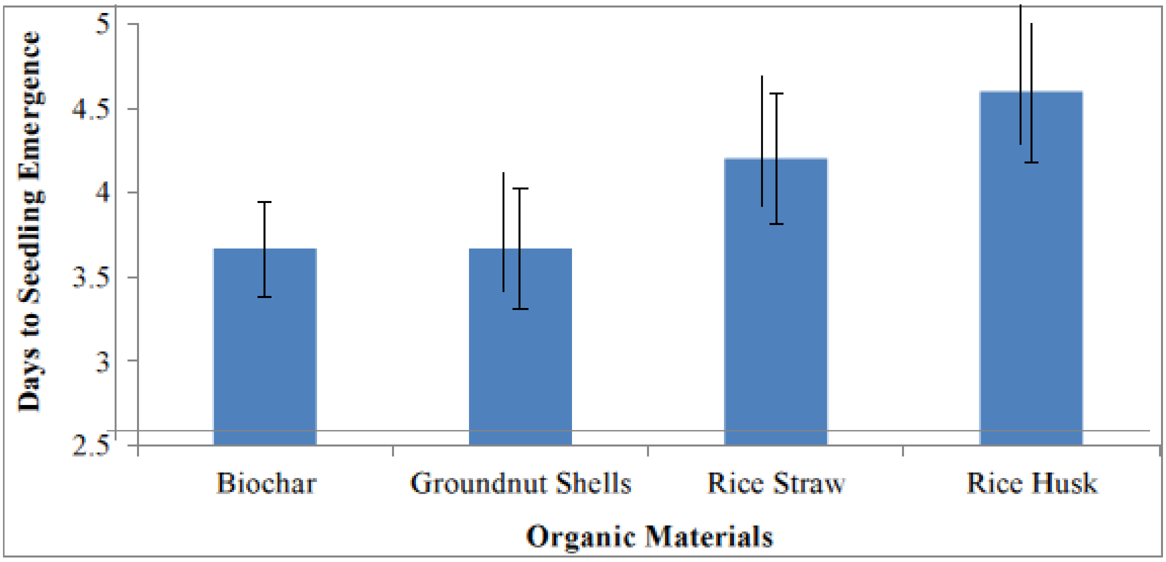

Figure 1: Effect of different organic materials on days to emergence of Maize cultivated in the Guinea savannah zone of Ghana. Bars represent the SEM.

Also, days to emergence was determined (*p<0.001*) by days after incorporation of organic materials. 28 and 35 days after incorporation of organic material took the shortest days to emerge and were similar to 21 days after incorporation of the organic materials. 7 and 14 days after incorporation of the organic materials took the longer days to emerge. Figure 2 shows the main effect of planting dates on emergence days.

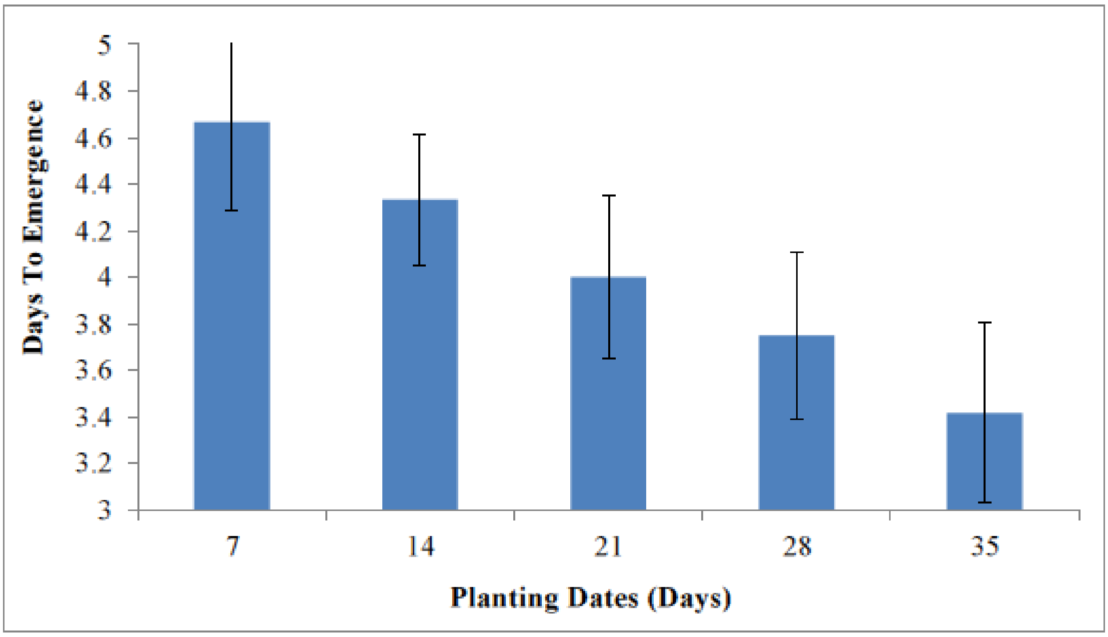

Figure 2: Effect of days after incorporation different organic materials on days to emergence of Maize cultivated in the Guinea savannah zone of Ghana. Bars represent the SEM.

4.1.2 Plant Height

Plant height was determined (*p<0.001*) by organic materials application from 2 to 6 WAP. Biochar gave the highest plant height and was similar to Groundnut Shells. Rice Husk produced the lowest plant height and was similar to Rice Straw. Possibly, Biochar and Groundnut Shells promoted fast maize growth and development of the plants. Figure 3 below depicts the main effects of organic materials on plant height.

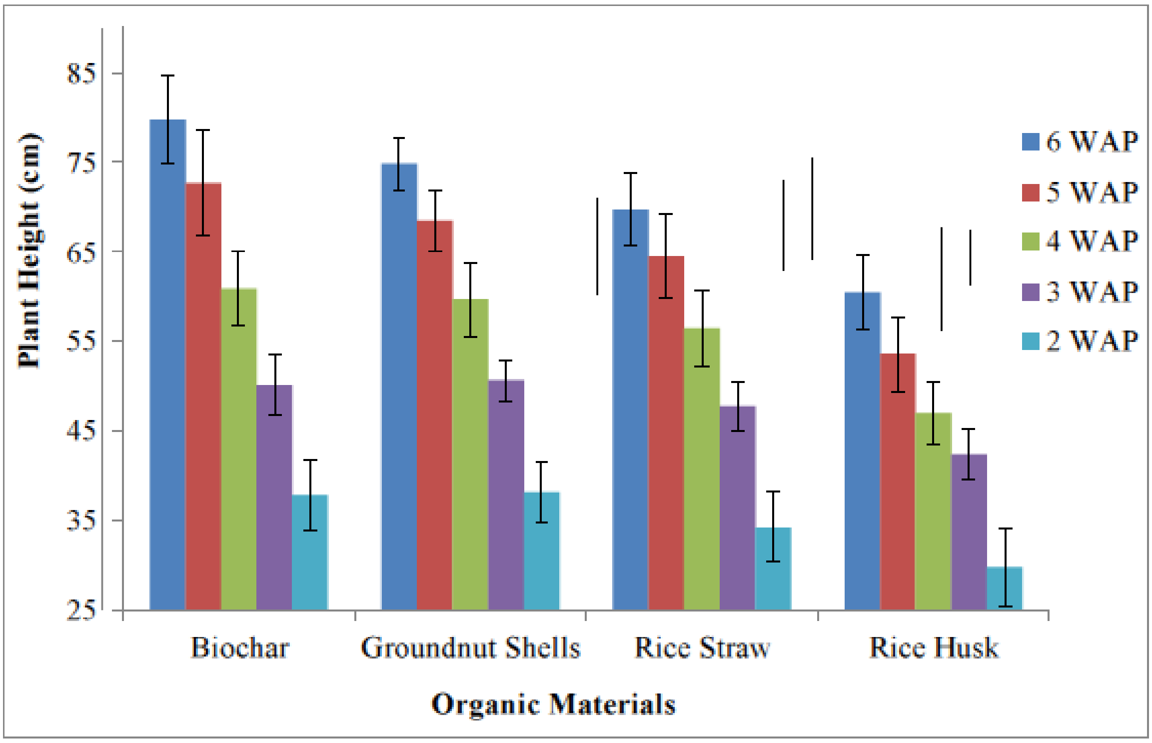

Figure 3: Effect of different organic materials on plant height of Maize cultivated in the Guinea savannah zone of Ghana. Bars represent the SEM.

Days after incorporation of the organic materials enhanced (*p=0.02*) plant height from 2 to 6 WAP. 14 days after incorporation of organic materials had the highest plant height in all the weeks and was at par with 21, 28 and 35 days after incorporation of the organic materials. However, 7 days after incorporation of organic materials gave the lowest heights across all the weeks. Figure 4 depicts the main effects of planting dates on plant height.

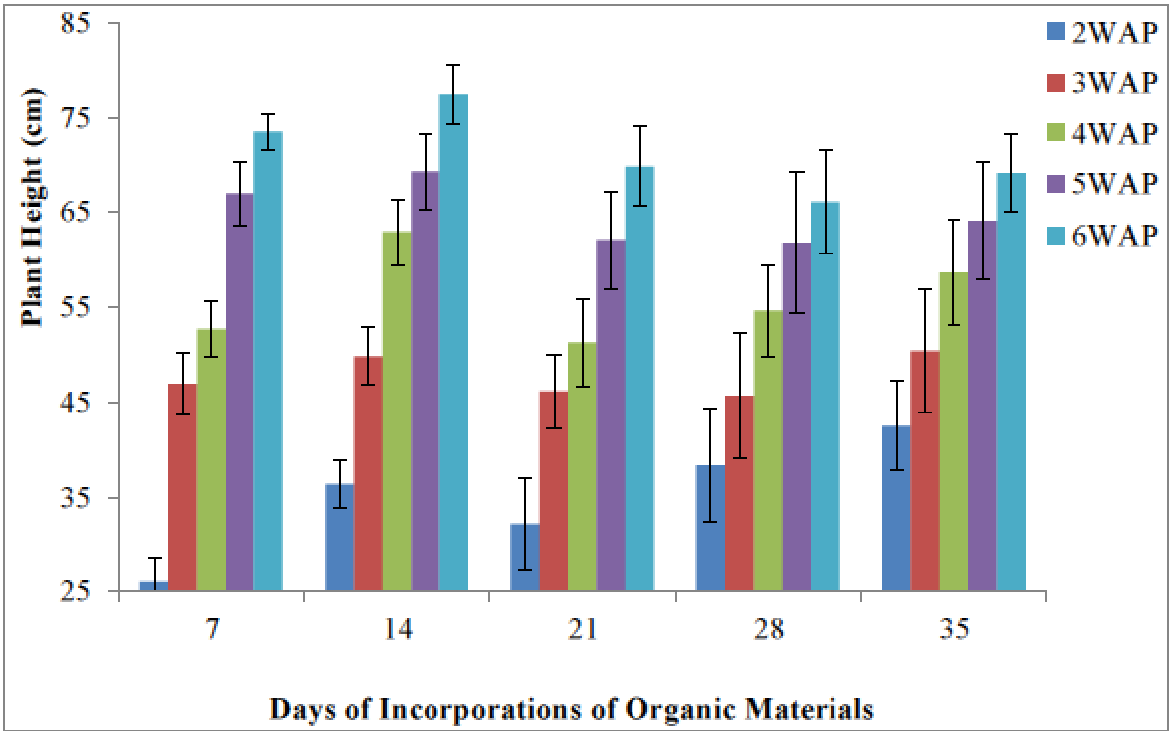

Figure 4: Effect of days after incorporation of different organic materials on plant height of Maize cultivated in the Guinea savannah zone of Ghana. Bars represent the SEM.

4.1.3 Leaf Count

The number of leaves was influenced ($p<0.001$) by the organic materials applications from 3 to 6WAP. Biochar and Groundnut Shells produced the maximum number of leaves and were similar. Rice Straw and Rice Husk recorded the least number of leaves. Figure 5**Error! Reference source not found.** shows the main effect of organic materials on leaf count of maize.

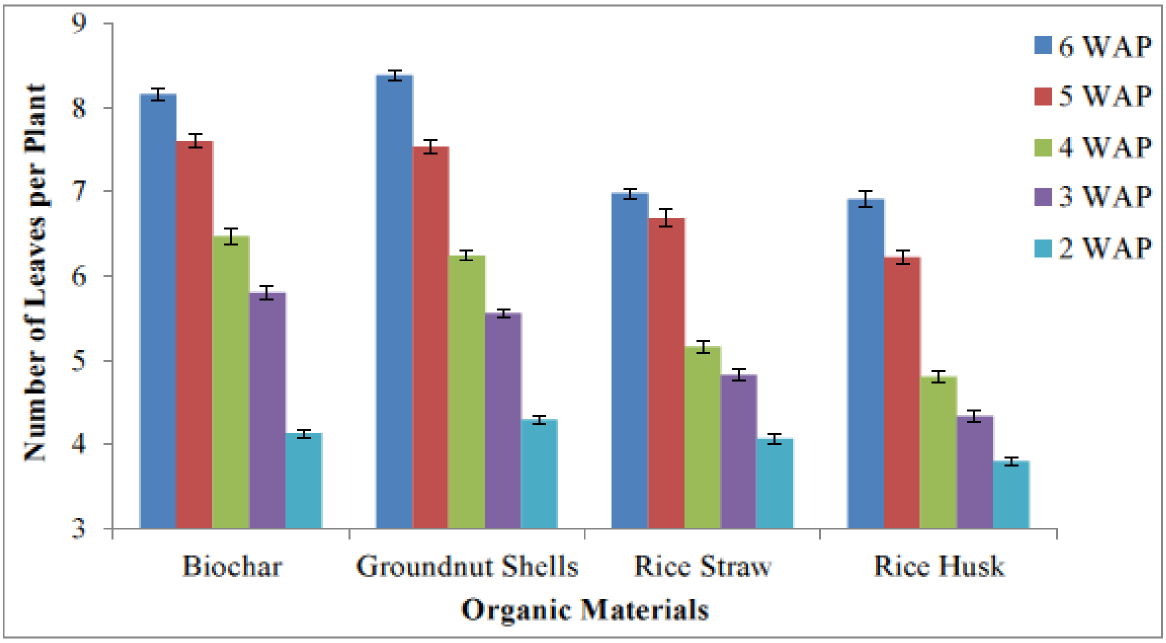

Figure 5: Effect of different organic materials on leaf count of Maize cultivated in the Guinea savannah zone of Ghana. Bars represent the SEM.

Also, days after incorporation of the organic materials enhanced (*p<0.001*) number of leaves. At 2WAP, 14 days after incorporation had the highest number of leaves compared to 21, 28 and 35 days after incorporation of the organic materials. At 4WAP, 28 and 35 days after incorporation had the highest number of leaves and similar to 21 days after incorporation. 14 days after incorporation gave the greatest leaf number and was at par with 21, 28 and 35 at 5WAP. 35 days after incorporation produced the highest number of leaves at 6WAP and was dissimilar to 21 and 28 days after incorporation. However, 7 days after incorporation of organic materials had the least number of leaves across all the weeks. Figure 6 shows the main effects of planting dates on number of leaves of maize.

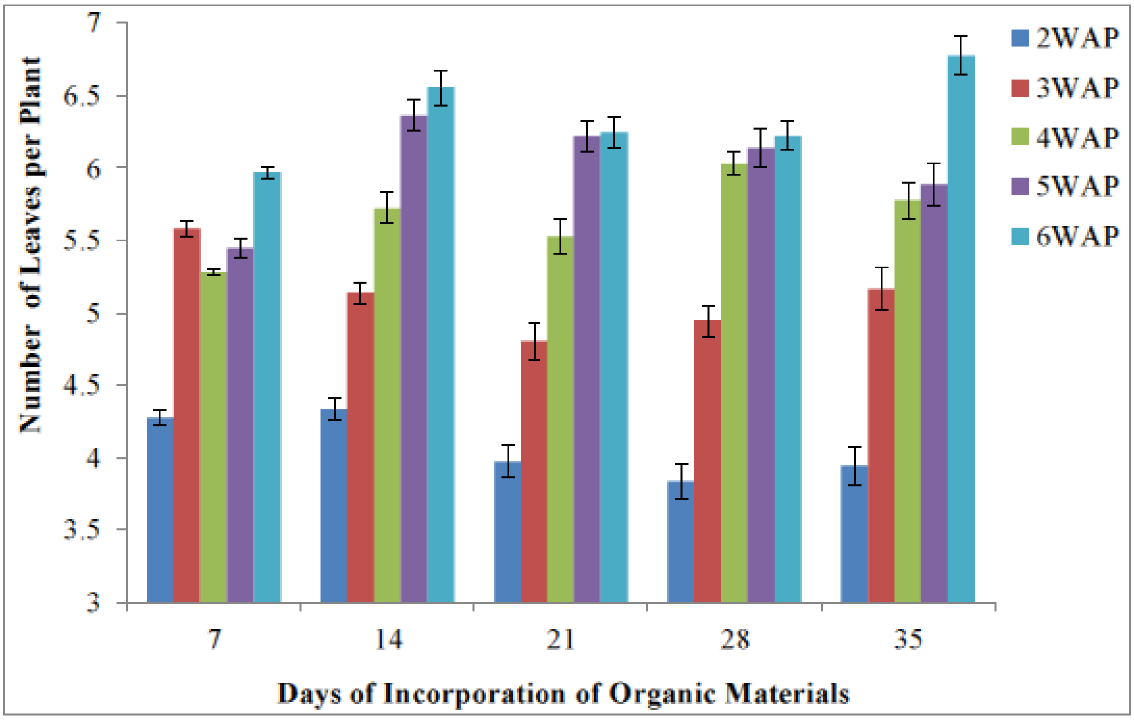

Figure 6: Effect of days after incorporation of different organic materials on leaf count of Maize cultivated in the Guinea savannah zone of Ghana. Bars represent the SEM.

4.1.4 Total Dry Matter

Total dry mater was influenced (*p<0.001*) by the application of the organic materials. Groundnut Shells similar to Biochar produced the maximum total dry matter. However, Rice Husk and Rice Straw were the same and gave least total dry matter. Figure 7 below depicts the effects of organic materials on total dry matter of maize.

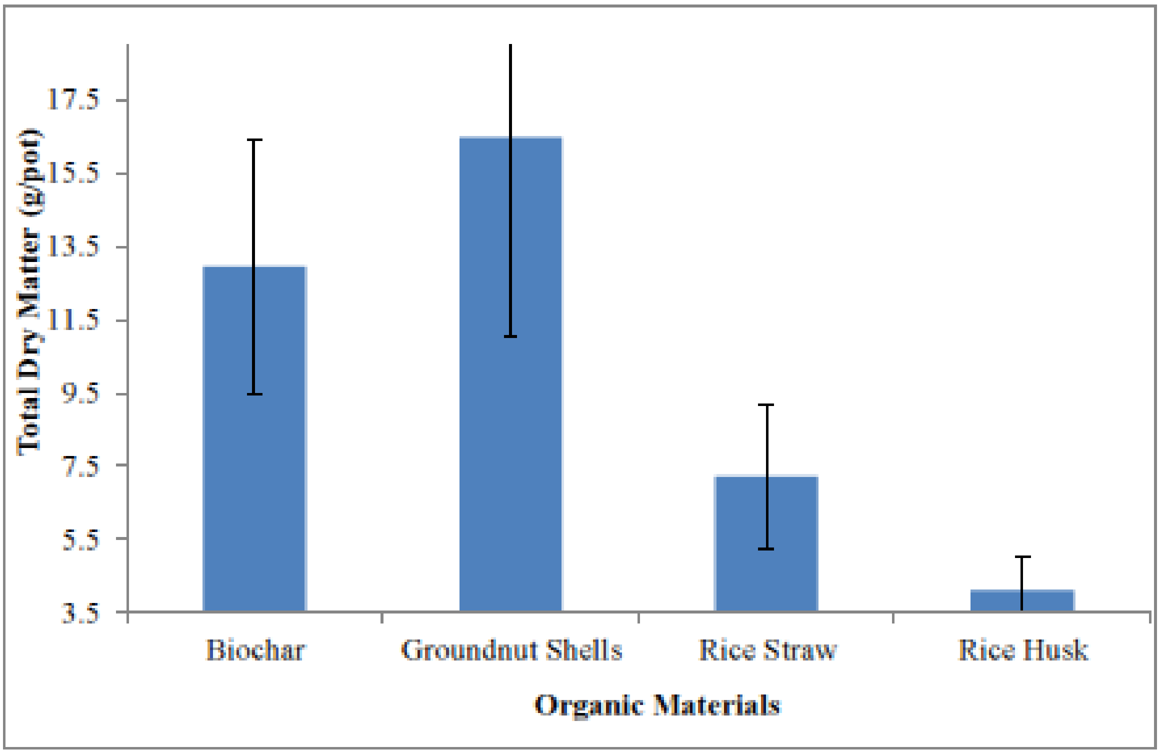

Figure 7: Effect of different organic materials on total dry matter of Maize cultivated in the Guinea savannah zone of Ghana. Bars represent the SEM.

Also, days after incorporation of these organic materials influenced (*p<0.001*) total dry matter 35 and 28 days after incorporation of organic materials produced the maximum total dry matter and were similar 21 days after incorporation of the organic materials. However, 7 recorded the lowest total dry matter. Figure 8 below confirms the main effects of planting dates on total dry matter weight.

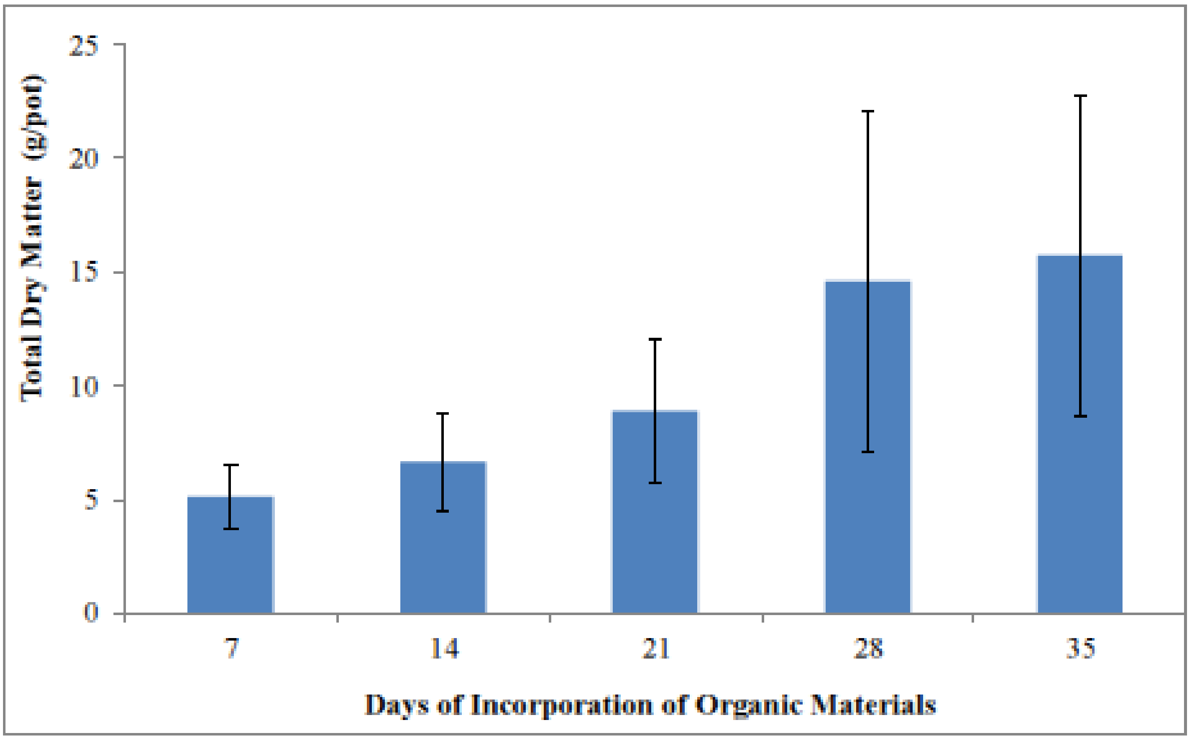

Figure 8: Effect of days of incorporation of different organic materials on total dry matter of Maize cultivated in the Guinea savannah zone of Ghana. Bars represent the SEM.

4.2 Field Trial

4.2.1 General Observation

Maize plots without inorganic fertilizer were looking yellowish-green and weak. There were no incidence of pests and diseases. Plots fertilized with inorganic fertilizer were frequently infested with weeds especially plots treated with the full rate of inorganic fertilizer (NPK).

4.2.2 Plant Height

Plant height was determined ($p<0.001$) by the treatments. The result also showed that increasing the rates of each amendment resulted to an increase in plant height. Maize height increased with time peaking at 9WAP. Highest plants were obtained with treatments of 7.5 t/ha Biochar + FNPK and 7.5 t/ha Biochar + Y2 NPK and were at par with 5 t/ha Biochar + FNPK, 7.5 t/ha Rice Husk + Y2 NPK, 5 t/ha Rice Straw + Y2 NPK and 7.5 t/ha Rice Straw + Y2 NPK at 9 WAP. However, the lowest plant height was produced by the control and RS1. Table 5 below depicts the means, the CV (%) and LSD values of plant height at 9 WAP.

Table 5: Plant Height of Maize at 9 WAP during 2014 cropping season

TREATMENT	Plant Height at 9 WAP (cm)
Control	176.8cd
2.5 t/ha Biochar	186.9bc
5 t/ha Biochar	186.4bc
7.5 t/ha Biochar	182.4bc
2.5 t/ha Groundnut Shells	191.0abc
5 t/ha Groundnut Shells	185.0bc
7.5 t/ha Groundnut Shells	172.4d
2.5 t/ha Rice Husk	182.5bc
5 t/ha Rice Husk	180.8bc
7.5 t/ha Rice Husk	183.3bc
2.5 t/ha Rice Straw	164.5d
5 t/ha Rice Straw	174.5cd
7.5 t/ha Rice Straw	180.6bc
2.5 t/ha Biochar + 1/2 NPK	190.7abc
5 t/ha Biochar + 1/2 NPK	194.7abc
7.5 t/ha Biochar + 1/2 NPK	201.2a
2.5 t/ha Groundnut Shells + 1/2 NPK	191.4abc
5 t/ha Groundnut Shells + 1/2 NPK	190.8abc
7.5 t/ha Groundnut Shells + 1/2NPK	185.3bc
2.5 t/ha Rice Husk + 1/2 NPK	188.3bc

Figures with the same letters are not significantly different from each other. NB: Y2 NPK = 45-30-30 kg NPK/ha.

Table 6: Plant Height of Maize at 9 WAP during 2014 cropping season

TREATMENT	Plant Height at 9 WAP (cm)
5 t/ha Rice Husk + Y2 NPK	189.0bc
7.5 t/ha Rice Husk + Y2 NPK	197.2ab
2.5 t/ha Rice Straw + Y2 NPK	190.6abc
5 t/ha Rice Straw + Y2 NPK	192.2abc
7.5 t/ha Rice Straw + Y2 NPK	193.3abc
2.5 t/ha Biochar + FNPK	193.1abc
5 t/ha Biochar + FNPK	199.4ab
7.5 t/ha Biochar + FNPK	200.5a
2.5 t/ha Groundnut Shells + FNPK	195.4abc
5 t/ha Groundnut Shells + FNPK	178.8bc
7.5 t/ha Groundnut Shells + FNPK	190.4abc
2.5 t/ha Rice Husk + FNPK	190.6abc
5 t/ha Rice Husk + FNPK	178.6cd
7.5 t/ha Rice Husk + FNPK	185.1bc
2.5 t/ha Rice Straw + FNPK	188.7bc
5 t/ha Rice Straw + FNPK	184.1
7.5 t/ha Rice Straw + FNPK	190.5abc
GRAND MEAN	187.2
LSD	14
CV (%)	5.3

Figures with the same letters are not significantly different from each other. NB: Y2 NPK = 45-30-30 kg NPK/ha and FNPK = 90-60-60 kg NPK/ha.

4.2.3 Leaf Count

The application of the treatments influenced (*p<0.001*) number of leaves from planting and peaking at 9 WAP. The number of leaves was enhanced by the application of 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + Y2 NPK, 2.5 Biochar + Y2 NPK, 5 t/ha Biochar +

FNPK and 7.5 t/ha Rice Straw + Y2 NPK at 9 WAP. The control gave the lowest. The table below displays the means, CV (%) and LSD of leaf count (Table 7).

Table 7: Leaf Count of Maize at 9 WAP during 2014 cropping season.

TREATMENT	LEAF COUNT AT 9 WAP
Control	10b
2.5 t/ha Biochar	11a
5 t/ha Biochar	11a
7.5 t/ha Biochar	11a
2.5 t/ha Groundnut Shells	11a
5 t/ha Groundnut Shells	11a
7.5 t/ha Groundnut Shells	11a
2.5 t/ha Rice Husk	10b
5 t/ha Rice Husk	10b
7.5 t/ha Rice Husk	11a
2.5 t/ha Rice Straw	11a
5 t/ha Rice Straw	11a
7.5 t/ha Rice Straw	11a
2.5 t/ha Biochar + Y2 NPK	11a
5 t/ha Biochar + Y2 NPK	11a
7.5 t/ha Biochar + Y2 NPK	11a
2.5 t/ha Groundnut Shells + Y2 NPK	11a
5 t/ha Groundnut Shells + Y2 NPK	11a
7.5 t/ha Groundnut Shells + Y2 NPK	11a
2.5 t/ha Rice Husk + Y2 NPK	11a

Figures with the same letters are not significantly different from each other. NB: Y2 NPK = 45-30-30 kg NPK/ha.

Table 8: Leaf Count of Maize at 9 WAP during 2014 cropping season.

TREATMENT	LEAF COUNT AT 9 WAP
5 t/ha Rice Husk + Y2 NPK	11a
7.5 t/ha Rice Husk + Y2 NPK	11a
2.5 t/ha Rice Straw + Y2 NPK	11a
5 t/ha Rice Straw + Y2 NPK	11a
7.5 t/ha Rice Straw + Y2 NPK	11a
2.5 t/ha Biochar + FNPK	11a
5 t/ha Biochar + FNPK	11a
7.5 t/ha Biochar + FNPK	11a
2.5 t/ha Groundnut Shells + FNPK	11a
5 t/ha Groundnut Shells + FNPK	11a
7.5 t/ha Groundnut Shells + FNPK	11a
2.5 t/ha Rice Husk + FNPK	10b
5 t/ha Rice Husk + FNPK	11a
7.5 t/ha Rice Husk + FNPK	11a
2.5 t/ha Rice Straw + FNPK	11a
5 t/ha Rice Straw + FNPK	11a
7.5 t/ha Rice Straw + FNPK	11a
GRAND MEAN	11
LSD	0.67
CV (%)	4.4

Figures with the same letters are not significantly different from each other. NB: Y2 NPK = 45-30-30 kg NPK/ha and FNPK = 90-60-60 kg NPK/ha.

4.2.4 Days to 50% Flowering

The treatments influenced ($p<0.001$) days to 50% tasselling of maize. 7.5 t/ha Biochar + FNPK took lesser days to tassel and were indifferent to 7.5 t/ha Biochar + Y2 NPK, 5 t/ha Biochar + FNPK, 5 t/ha Biochar + Y2 NPK, 7.5 t/ha Rice Straw + FNPK and 7.5 t/ha Rice

Straw + Y2 NPK. As expected, the control took longer days to flower. The figure below shows the effect of treatments on days to 50% flowering.

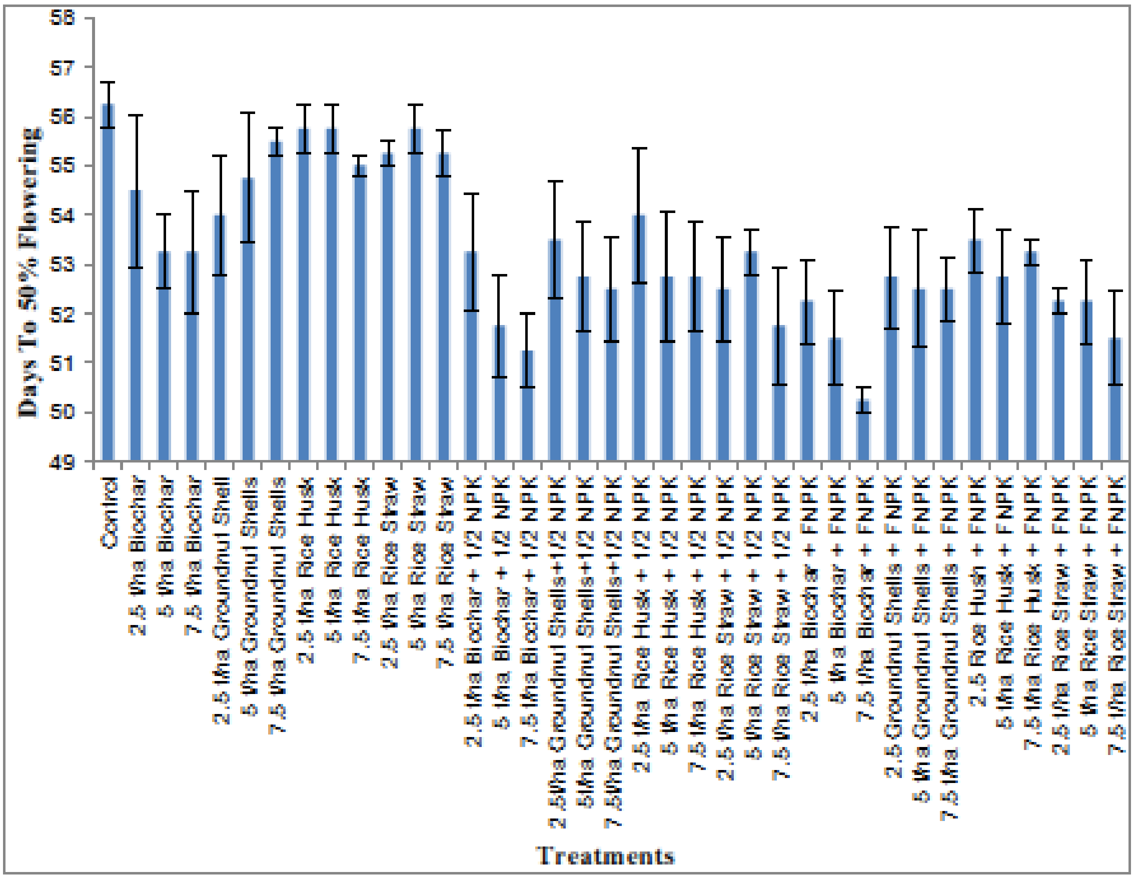

Figure 9: Effect of treatments on Days to 50% Flowering of Maize cultivated in the Guinea Savannah zone of Ghana. Bars represent SEMs. NB: 1/2 NPK = 45-30-30 kg NPK/ha and FNPK = 90-60-60 kg NPK/ha.

4.2.5 Height of Cob Attachment

The height of cob attachment was determined (*p<0.001*) by the organic materials with the application of 7.5 t/ha Biochar + FNPK given the highest and was at par with 7.5 t/ha Biochar + Y2 NPK, 5 t/ha Groundnut Shells + FNPK, 5 t/ha Biochar + FNPK, 5 t/ha Rice Straw + Y2 NPK and 5 t/ha Rice Straw + FNPK. The control had the shortest height of cob attachment as expected. Figure 10Error! Reference source not found. below effect of treatments on height of cob attachment.

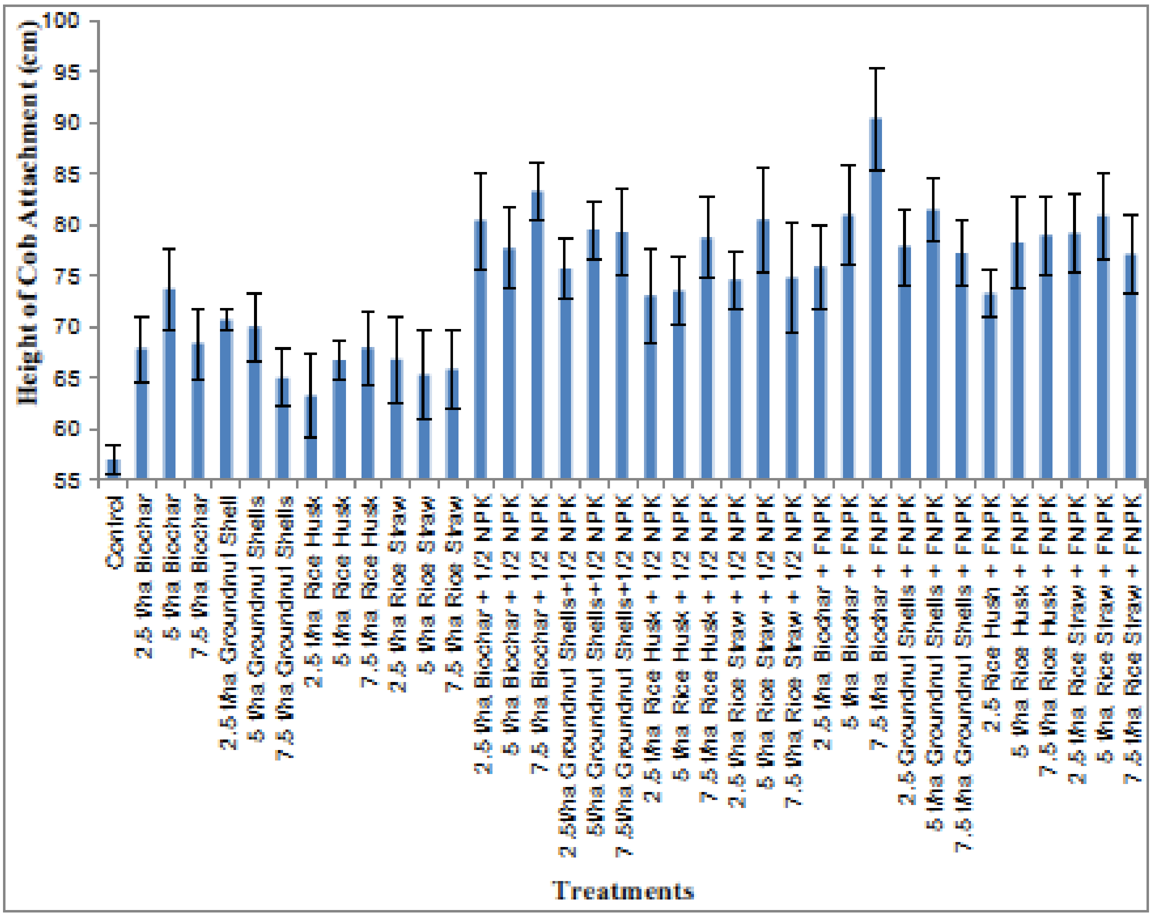

Figure 10: Effect of treatments on Height of Cob Attachment of Maize cultivated in the Guinea Savannah zone of Ghana. Bars represent SEMs. NB: 1/2 NPK = 45-30-30 kg NPK/ha and FNPK = 90-60-60 kg NPK/ha.

4.2.6 Cob Length

Cob length was enhanced (*p<0.001*) by the treatments. The application of 7.5 t/ha Biochar + FNPK and 7.5 t/ha Biochar + Y2 NPK produced the longest cob that were indifferent to 7.5 t/ha Groundnut Shells + Y2 NPK, 7.5 t/ha Rice Husk + Y2 NPK, 5 t/ha Groundnut Shells + FNPK, 5 t/ha Biochar + Y2 NPK and 7.5 t/ha Rice Husk + FNPK. The control gave the shortest cob. Figure 11 displaying the effect of treatments on cob length.

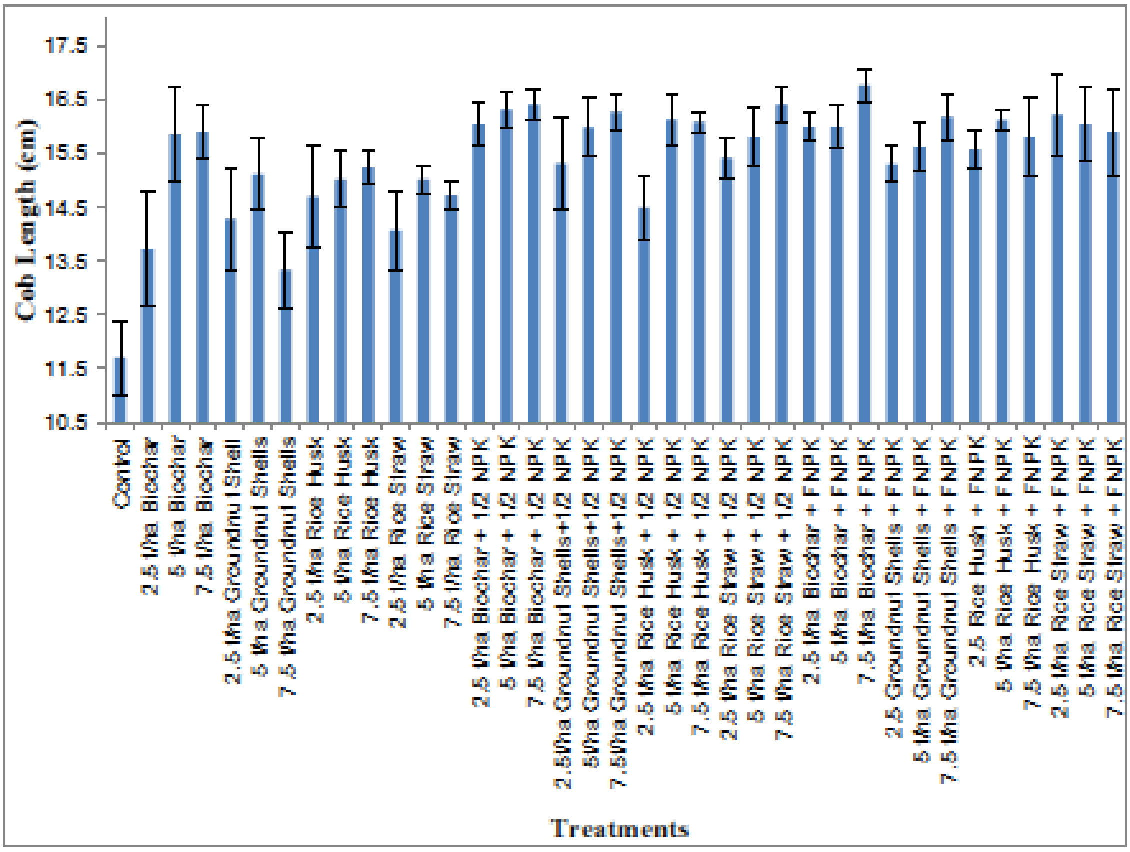

Figure 11: Effect of treatments on Cob Length of Maize cultivated in the Guinea savannah zone of Ghana. Bars represent SEMs. NB: 1/2 NPK = 45-30-30 kg NPK/ha and FNPK = 90-60-60 kg NPK/ha.

4.2.7 Cob Weight

All the treatments enhanced (*p<0.001*) cob weight at harvest. The outstanding treatments were: 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + Y2 NPK, 5 t/ha Biochar + FNPK, 5 t/ha Biochar + Y2 NPK, 2.5 t/ha Biochar + FNPK, 7.5 Groundnut Shells + FNPK, 5 t/ha Groundnut Shells + Y2 NPK, 7.5 t/ha Rice Straw + Y2 NPK and 7.5 t/ha Rice Straw + FNPK, which were similar. As expected, the control had the minimum cob weight. The figure below depicts the effect of treatments on cob weight.

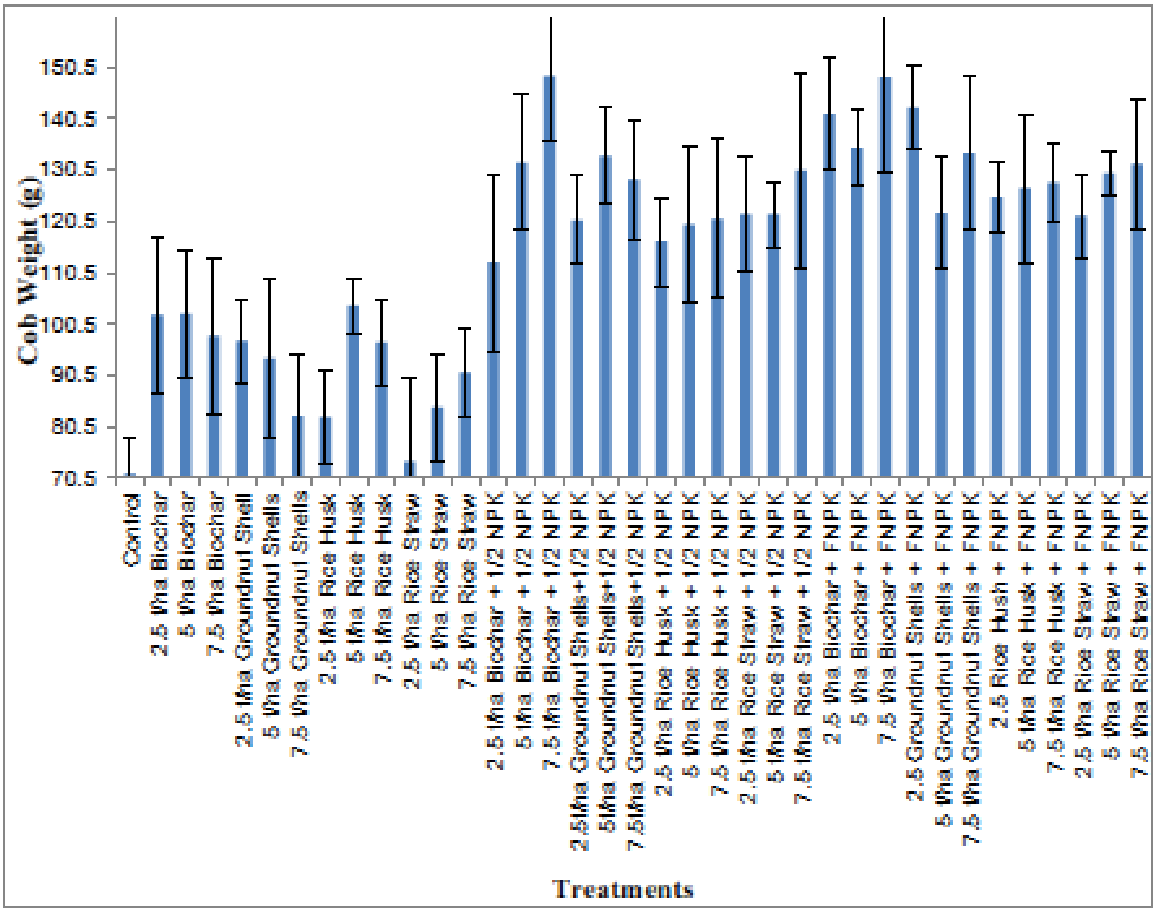

Figure 12: Effect of treatments on Cob Weight of Maize cultivated in the Guinea Savannah zone of Ghana. Bars represent SEMs. NB: 1/2 NPK = 45-30-30 kg NPK/ha and 90-60-60 kg NPK/ha.

4.2.8 Grain Yield

The grain yield was highly affected (*p<0.001*) by the application of the organic materials. The 5 outstanding treatments were: 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + Y2 NPK, 7.5 t/ha Groundnut Shells + FNPK, 7.5 t/ha Rice Husk + FNPK and 7.5 t/ha Rice Straw + FNPK, which were at par with 7.5 t/ha Groundnut Shells + Y2 NPK, 2.5 t/ha Groundnut Shells + FNPK and 5 t/ha Biochar + FNPK. However, the control and 2.5 t/ha Rice Straw gave the lowest grain yields. Figure 13 depicts the effect of treatments on grain yield.

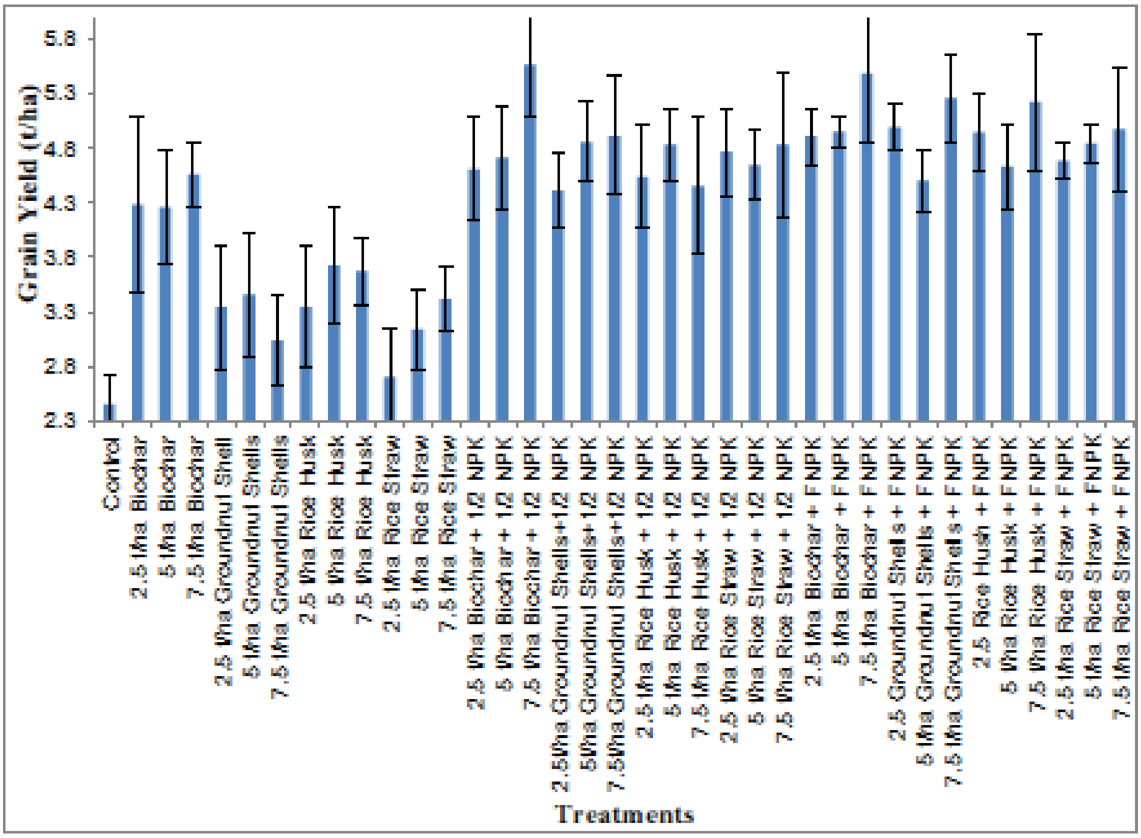

Figure 13: Effect of treatments on Grain Yield of Maize cultivated in the Guinea Savannah zone of Ghana. Bars represent SEMs. NB: 1/2 NPK = 45-30-30 kg NPK/ha and FNPK = 90-60-60 kg NPK/ha.

4.2.9 100 Seed Weight

The application of the organic materials influenced (*p<0.001*) 100 seed weight. The outstanding treatments were: 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + Y2 NPK, 7.5 t/ha Rice Husk + FNPK, 7.5 t/ha Groundnut Shell + FNPK, 7.5 t/ha Groundnut Shells + Y2 NPK, 7.5 t/ha Rice Husk + Y2 NPK, 7.5 t/ha Rice Straw + FNPK and 7.5 t/ha Rice Straw + Y2 NPK. However, the control and 2.5 t/ha Rice Straw gave the least 100 seed weight. Figure 14 below displays the effect of treatments on 100 seed weight.

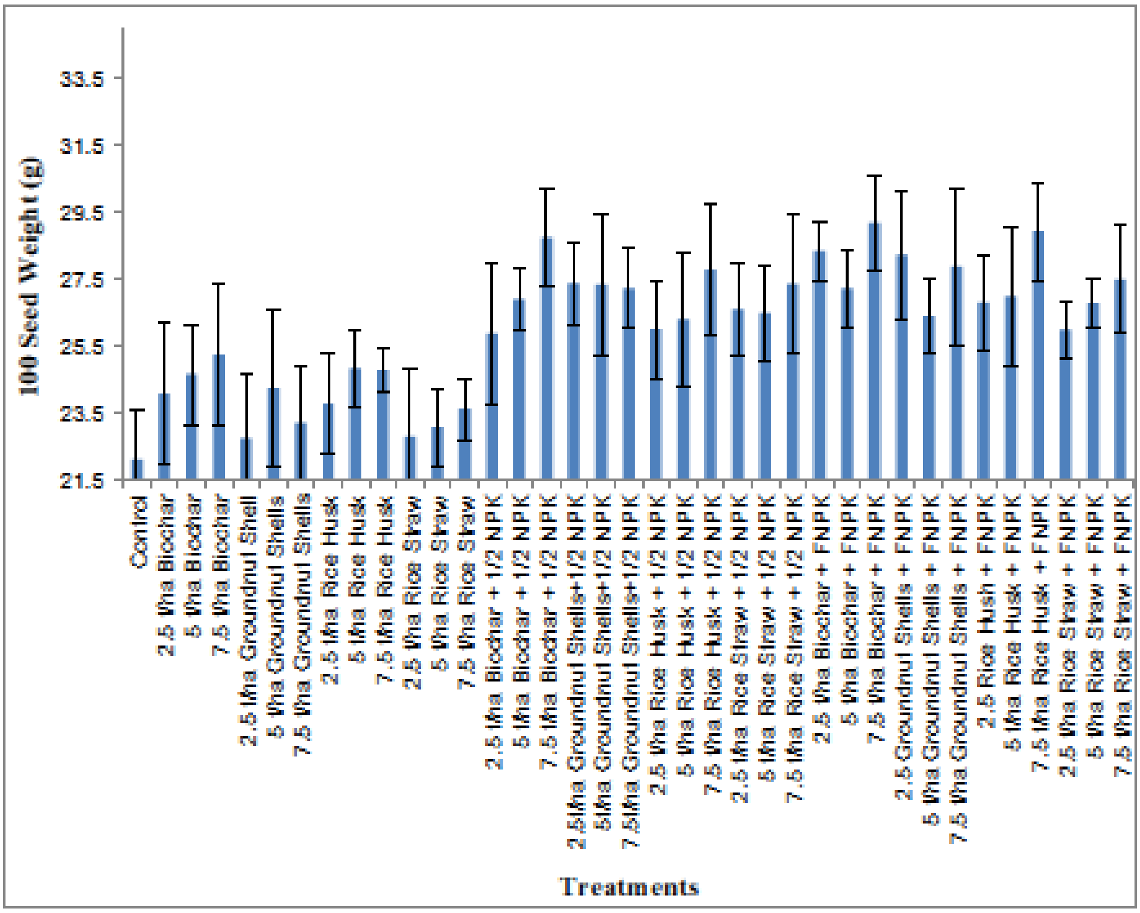

Figure 14: Effect of treatments on 100 Seed Weight of Maize cultivated in the Guinea Savannah zone of Ghana. Bars represent SEMs. NB: 1/2 NPK = 45-30-30 kg NPK/ha and FNPK = 90-60-60 kg NPK/ha.

4.2.10 Stover Weight

The stover weight of the maize plants was enhanced (*p<0.001*) by the application of the treatments. The outstanding 5 treatments were: 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + V2 NPK, 7.5 t/ha Groundnut Shells + FNPK, 7.5 t/ha Groundnut Shells + V2 NPK and 5 t/ha Biochar + FNPK, and were indifferent to 5 t/ha Biochar + V2 NPK, 7.5 t/ha Rice Husk + V2 NPK, 5 t/ha Rice Straw + FNPK and 5 t/ha Rice Husk + V2 NPK. Obviously, the control gave the lowest stover weight. Figure 15 below depicts the effect of the treatments on stover weight of maize.

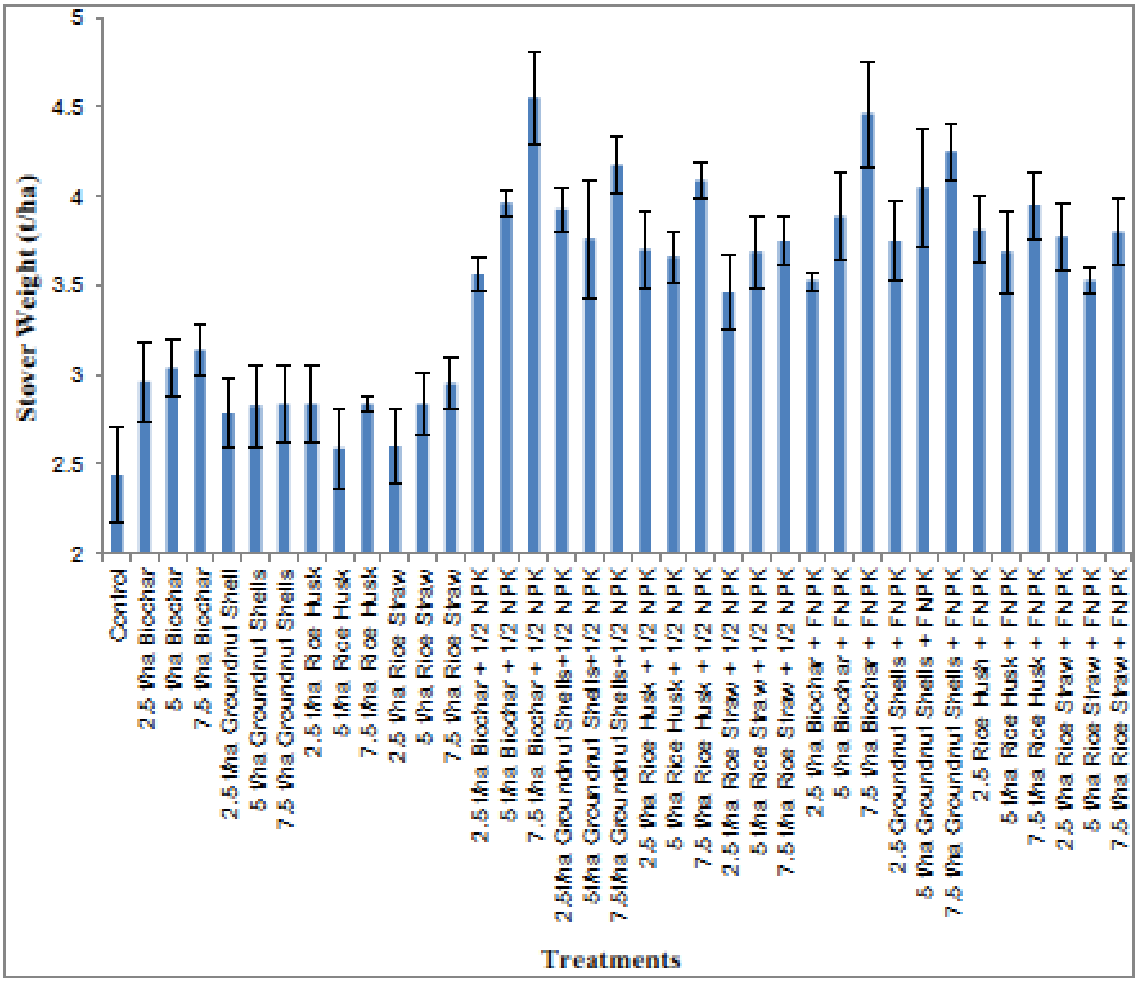

Figure 15: Effect of treatments on Stover Weight of Maize cultivated in the Guinea Savannah zone of Ghana. Bars represent SEMs. NB: 1/2 NPK = 45-30-30 kg NPK/ha and FNPK = 90-60-60 kg NPK/ha.

4.3 Regression Analysis

4.3.1 Regression between Grain Yield and Cob Weight

Cob weight influenced grain yield at harvest. The regression analysis shows grain yield at harvest was determined by cob weight. The R^2 value is 88.92%. This indicates that 88.92% of the variation in the grain yield values can be explained by the linear relationship with cob weight. There is a strong relationship between grain yield and cob weight since all the points are very close to the line of best fit. The figure below depicts the linear relationship between grain yield and cob weight.

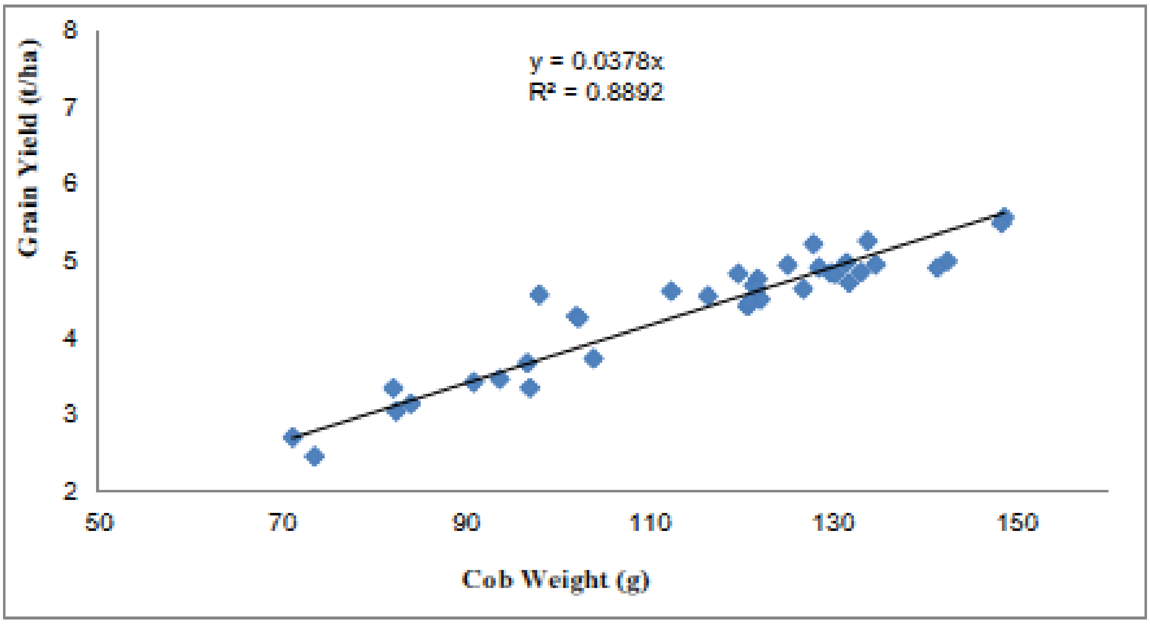

Figure 16: Linear relationship between Grain Yield and Cob Weight.

4.3.2 Regression between Grain Yield and 100 Seed Weight

100 seed weight also influenced grain yield significantly at harvest. The regression analysis shows grain yield at harvest was determined by grain weight. The R^2 value is 86.27%. This indicates that 86.27% of the variation in the grain yield values can be explained by the linear relationship with 100 seed weight. There is a strong relationship between grain yield and 100 seed weight, since all the points are very close to the line of best fit. The figure below depicts the linear relationship between grain yield and 100 seed weight.

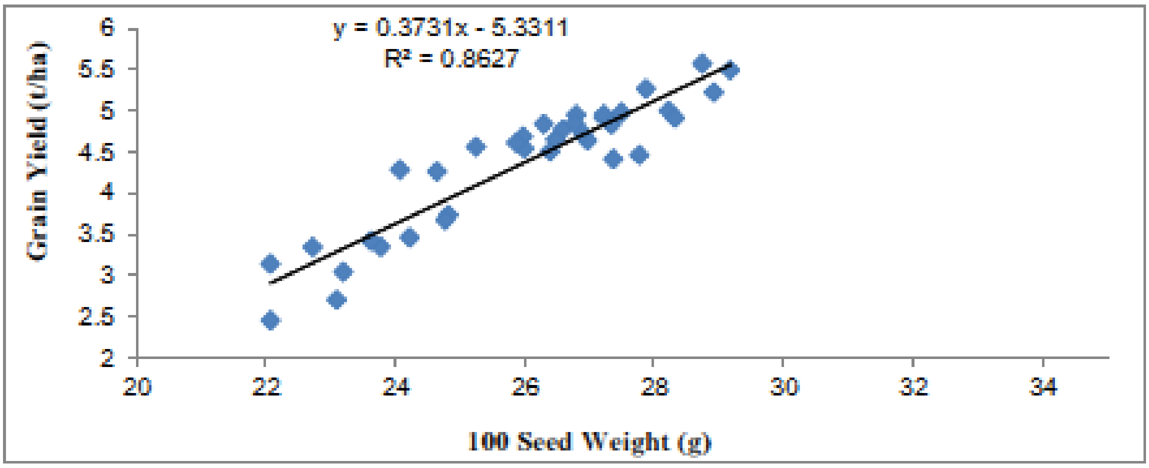

Figure 17: Linear relationship between Grain Yield and 100 Seed Weight

4.3.3 Regression between Grain Yield and Stover Weight

Stover weight also influenced grain yield significantly at harvest. The regression analysis indicated that grain yield at harvest was determined by stover weight. The R^2 value is 79.18%. This indicates that 79.18% of the variation in the grain yield values can be explained by the linear relationship with stover weight. There is a strong relationship between grain yield and stover weight, since all the points are very close to the line of best fit. The figure below depicts the linear relationship between grain yield and stover weight.

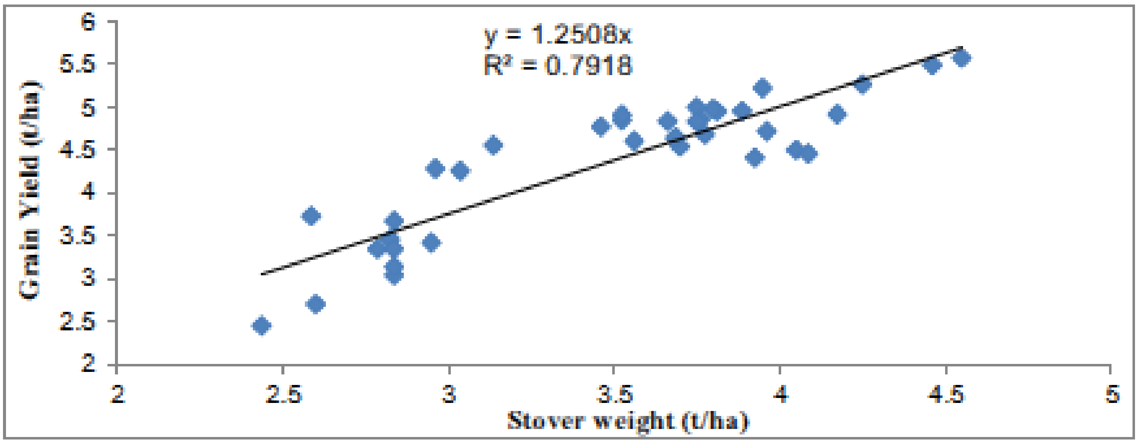

Figure 18: Linear relationship between Grain Yield and Stover Weight

4.4 Soil Analysis at Harvest

Soil analysis at harvest showed that the treatments influenced the physio-chemical properties of the soil over the control. The treatments influenced the pH of the soil. The treatments increased the organic carbon content and the major plant nutrient elements (nitrogen, phosphorus, potassium, calcium and magnesium) of the soil. The table below depicts the results of soil physio-chemical analysis after harvesting.

Table 9: Soil Analysis after Harvesting

								SOIL TEXTURE		
TREATMENT	pH	% OC	% N	Mg/kg P	Mg/kg K	Mg/kg Ca	Mg/kg Mg	% SAND	% CLAY	% SILT
Control	5.5	0.1	0.01	3.6	51.8	64.7	27.88	90.4	1.3	8.4
BC1	5.3	0.8	0.07	5.8	74	114.6	78.7	77.4	6.3	16.2
BC2	5.3	0.7	0.07	5.8	69.7	167.5	75.7	89.3	2.7	7.9
BC3	5.4	1.6	0.15	11.9	59.4	174.7	73.5	79.4	3.4	17.3
GS1	5.5	0.8	0.07	8.9	98.5	64.7	47.3	90.5	2.4	7.2
GS2	5.1	2.9	0.28	8.7	55	178.9	72.5	79.3	8.8	12.0
GS3	5.1	2.8	0.28	8	151.8	245.8	87.6	88.4	3.3	8.4
RH1	5.5	0.7	0.06	6	61.3	124.5	44	87.5	8.4	4.1
RH2	5.4	0.7	0.07	5	58.6	117.6	34.7	88.3	3.8	7.9
RH3	5.1	0.7	0.07	6	114.3	134.3	42.3	89.5	4.3	6.2
RS1	4.8	2.9	0.27	8.5	52.7	198.8	61.7	66.3	7.8	26.0
RS2	5.1	3.1	0.29	11.1	59.4	235	73	68.3	4.7	24.0
RS3	5.1	2.9	0.28	9.7	98.5	199.7	62.5	70.5	3.3	26.2
BC1 + 1/2 NPK	5.3	1.0	0.09	8.7	105.6	143.7	44.8	72.5	9.3	18.1
BC2 + 1/2 NPK	5.3	0.9	0.08	7.5	98.6	197.9	87.8	72.3	8.7	18.9
BC3 + 1/2 NPK	5.4	0.8	0.08	7.7	51.8	118.7	62.8	81.4	5.3	13.4
GS1 + 1/2 NPK	5.4	1.7	0.16	12.8	61.3	186.8	65.6	67.5	8.4	24.2
GS2 + 1/2 NPK	4.5	3.0	0.29	10.6	58.6	164.7	88.7	69.3	9.8	21.0

Table 6: Soil Analysis after Harvesting

TREATMENT	pH	% OC	% N	Mg/kg P	Mg/kg K	Mg/kg Ca	Mg/kg Mg	SOIL TEXTURE % SAND	% CLAY	% SILT
GS3 + 1/2NPK	5.1	2.7	0.26	6.8	114.3	214.4	72.9	85.5	8.4	6.2
RH1 + 1/2 NPK	5.2	0.9	0.09	7.9	52.7	153.8	52.8	85.3	6.8	7.9
RH2 + 1/2 NPK	5.1	0.4	0.04	4.5	59.4	82.7	32.7	91.3	4.8	3.9
RH3 + 1/2 NPK	5.1	0.7	0.06	5.5	98.5	118.8	35.2	88.5	6.3	5.2
RS1 + 1/2 NPK	5.2	3.1	0.3	12.7	55	247.5	74.8	63.3	4.8	32.0
RS2 + 1/2 NPK	5.1	3.0	0.29	9.8	51.8	212.2	66.1	77.4	4.2	18.4
RS3 + 1/2 NPK	5.0	3.0	0.3	12	61.3	216.2	64	73.3	2.5	24.2
BC1 + FNPK	4.9	1.5	0.13	13.6	142.8	163.5	89	65.5	10.3	24.1
BC2 + FNPK	5.1	0.7	0.06	8.7	60.8	163.9	72.5	76.3	9.7	13.9
BC3 + FNPK	5.1	0.9	0.09	8.9	114.3	147.9	68.5	85.6	4.4	10.2
GS1 + FNPK	5.0	0.8	0.07	8.4	52.7	122.6	47.8	89.3	2.8	8.0
GS2 + FNPK	4.8	3.2	0.31	14.9	59.4	188.6	97.9	67.3	4.8	28.0
GS3 + FNPK	5.0	3.0	0.28	8.7	198.5	267	92.7	86.5	3.4	10.2
RH1 + FNPK	4.8	0.5	0.05	5.4	55	88.8	34	59.4	8.8	3.9
RH2 + FNPK	4.9	0.4	0.03	3.8	51.8	76	28.3	91.4	6.3	2.3
RH3 + FNPK	5.3	1.1	0.1	7	61.3	157.1	47.1	76.5	9.3	14.2
RS1 + FNPK	5.3	3.0	0.29	11.7	58.6	221.6	67.1	65.3	6.8	28.0
RS2 + FNPK	4.9	3.3	0.32	15.6	114.3	254.1	84.9	69.5	4.3	26.2
RS3 + FNPK	4.9	3.2	0.31	13.8	52.7	244.2	73.8	66.3	2.7	31.0

NB: (BC = Biochar, GS = Groundnut shells, RH = Rice husk and RS = Rice straw), (1 = 2.5 t/ha, 2 = 5 t/ha and 3 = 7.5 t/ha) and (1/2 NPK = 45-30-30 kg NPK/ha and FNPK = 9060-60 kg NPK/ha).

CHAPTER 5: DISCUSSION

5.1 Pot Trial

5.1.1 Days to Emergence

Days to seedlings emergence was positively affected by the application of the organic materials and planting dates after the incorporation of the organic materials. Shortest days to maize seedlings emergence were observed with Biochar and Groundnut Shells applications and are attributed to their faster decomposition rate which provided an ideal environment for the seedlings emergence.

Delayed planting after the incorporation of untreated organic materials promoted early crop emergence lending credence to findings that the organic materials required time for decomposition to reduce the C/N ratio to the level that could support plant growth (Pham *et al*., 2001). Therefore, optimum timing of planting is essential for efficient use of plant nutrients. For example, Pham *et al.* (2001) reported that rice straw can be composted rapidly within 45 days, although we observed that, under pot conditions, planting 21 days after the incorporation of the organic materials was adequate. Findings of Havlin *et al.* (2005) showed that 50 to 75% of total nitrogen contained in manure is organic and needs to undergo mineralization before it becomes available for plant uptake; with the remaining 25 to 50% being ammonium ($NH4^+$) and susceptible to volatilization.

5.1.2 Plant Height

Plant height indicates the influence of various nutrients on plant metabolism. The observed increment in height with Biochar comparable to Groundnut Shells (Figure 3) is attributed to nutrients availability especially nitrogen (Khan *et al*., 2008) which promoted fast growth and development of the maize plants. This result is in consonance with Yeboah *et al.* (2009) who observed that higher biochar applications increased crop nutrient uptake and growth rate. Vaccari *et al*. (2011) concluded that high rates of biochar application have no negative effects on wheat growth. Efthimiadou *et al.* (2010); Masulili *et al.* (2010); Nwaiwu *et al.* (2010) also observed that organic manure used alone ensured increment in growth of crop.

Planting 14 days after incorporation of organic materials similar to 21, 28 and 35 days (Figure 4) was enough to maximize plant height, as the parameter was probably not sensitive to the state of decomposition of the organic materials. This is attributed to the fact that the state of decomposition and mineralization at 14 days after incorporation of the organic materials enhanced nutrient availability especially nitrogen. This is in line with Havlin *et al.* (2005) who also observed that 50 to 75% of total nitrogen contained in manure is organic and needs to undergo mineralization before it becomes available for plants.

5.1.3 Leaf Count

The significant variation in maize leaf count is attributed to the organic material sources. The maximum number of leaves observed with Biochar and Groundnut Shells dissimilar to Rice Straw and Rice Husk (Figure 5) is attributed to nutrients availability especially nitrogen (Khan *et al*., 2008) provided by the organic materials which promoted fast growth and development of the maize plants. This is in line with Efthimiadou *et al.* (2010) who observed that organic soil amendments recorded the highest number of leaves. Previously, Okoruwa (1998) observed significant increases in Leaf Area Index in maize with biochar application. Widowati and Asnah (2014) also observed that the sole application of biochar increased relative agronomic effectiveness in maize production.

Credibly, date of planting after incorporation of the organic materials influenced leaf number differently, such that at least 14 days (Figure 6) of delay was required to optimize leaf production by maize plants. This is attributed to the fact that the organic materials were well decomposed between 14 to 35 days after incorporation and provided a good environment that enhanced maize growth and development.

5.1.4 Total Dry Matter

Total dry mater was influenced by the type of organic materials with groundnut shell and biochar maximizing production (Figure 7). Rice husk and, and rice straw supported the least amount of total dry matter accumulated. The organic materials improved crop growth as exhibited in increased plant height and dry biomass (Thomsen, 2005; Masulili *et al*., 2010) due to nutrient availability especially nitrogen (Khan *et al*., 2008). The result is in line with Baronti *et al.* (2010) who observed that biochar application increased dry matter increase by 120%. Previously, Ogbonna and Obi (2005) also observed an increased in high dry matter with organic manure application alone.

Late plantings between 21 to 35 days after incorporation of the organic materials favoured maximum total dry matter accumulation, relative to earlier dates of 7 to 14 days (Figure 8). This is attributed to the fact that the organic materials were well decomposed at 21 to 35 days and provided sufficient nutrients especially nitrogen for maize growth, development and enhanced dry matter accumulation. Optimum timing of application is a fundamental constituent to maximizing nitrogen use efficiency in organic manures and dry matter accumulation (Thomsen, 2005) concluded that management of manure fertilizers is difficult principally because organic materials are affected by the timing of incorporation and distribution. This is contrary to Onunka *et al.* (2012), who concluded that the time interval between 2-4 weeks after planting gave the highest economical root yield of sweet potato.

5.2 Field Trial

5.2.1 Plant Height

The plant height is not a yield component in grain crops but it indicates the influence of various nutrients on plant metabolism. The significant variation in maize plant height is influenced by the different organic materials sources and inorganic quantities. The observed increase in plant height by the applications of 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + V2 NPK, 5 t/ha Biochar + FNPK, 7.5 t/ha Rice Husk + V2 NPK, 2.5 t/ha Groundnut Shells + FNPK, 7.5 t/ha Rice Straw + V2 NPK, 7.5 t/ha Rice Straw + FNPK, 5 t/ha Rice Straw + V2 NPK compared to other treatments (Table 5) is attributed to nitrogen availability. This result is in line with Khan *et al.* (2008) who attributed plant height increment to positive effect of nitrogen on vigorous vegetative growth. Nwaiwu *et al.* (2010) also observed an increase in plant height when organic manure was used alone or in combination with inorganic fertilizer.

5.2.2 Leaf Count

The significant variation in maize leaf count is attributed to the organic material sources and inorganic fertilizer quantities. The increase in number of leaves observed by the application of 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + V2 NPK, 2.5 t/ha Biochar + V2 NPK, 5 t/ha Biochar + FNPK and 7.5 t/ha Rice Straw + V2 NPK (Table 7) was enhanced by the combined application of the organic materials and inorganic fertilizer. The organic materials and inorganic fertilizer provided an ideal environment for faster growth and establishment of maize and this was in accordance with Sadeghi and Bahrani (2009) who observed an optimum crop growth and development with the application of highest crop residues and nitrogen rates. Sutanto *et al.* (1993) also observed that farmyard manure and mineral fertilizer promoted sustainable food crop production on acid soils.

5.2.3 Days to 50% Flowering

Timely nutrients availability (mainly nitrogen) from the organic materials and inorganic fertilizer hastened maize growth and development. This positively changed the physiological functions of the maize crop. Shorter days to 50% flowering observed in 7.5 t/ha Biochar + FNPK comparable to 7.5 t/ha Biochar + Y2 NPK, 7.5 t/ha Rice Straw + FNPK, 7.5 t/ha Rice Straw + Y2 NPK, 5 t/ha Biochar + FNPK and 5 t/ha Biochar + Y2 NPK (Figure 9) are attributed to their enhancement in faster growth rate and enhanced development over other treatments. This result is in consonance with the work of Nwaiwu *et al.*, 2010 who observed an increment in plant growth and faster development when organic manure was used alone or in combination with inorganic fertilizer. However, Uzoma *et al.* (2011) observed that only organic amended soils resulted in better crop establishment and positively increased crop growth rate.

5.2.4 Height of Cob Attachment

Timely availability of nutrients mainly nitrogen from the organic sources and inorganic fertilizer rates increased maize growth. The organic materials and inorganic fertilizer synergistically increased the nutrient status of the soil as observed with the application of 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + Y2 NPK, 5 t/ha Biochar + FNPK, 5 t/ha Rice Straw + FNPK and 5 t/ha Rice Straw + Y2 NPK (Figure 10), which promoted maize growth. This observation is line with the work of Nwaiwu *et al.* (2010) who also observed that organic manure in combination with inorganic fertilizer led to increment in plant growth though, Masulili *et al*. (2010) observed that organic manure applied alone increased rice plant height.

5.2.5 Cob Length

Cob length is a yield component and a determinant of overall maize yield. Cob length of maize was significantly affected by various organic sources and their combinations with inorganic fertilizer. Lengthy cobs in 7.5 t/ha Biochar + FNPK and 7.5 t/ha Biochar + V2 NPK comparable to 7.5 t/ha Groundnut Shells + FNPK, 7.5 t/ha Groundnut Shells + V2 NPK, 7.5 t/ha Rice Straw + V2 NPK, 5 t/ha Biochar + V2 NPK, 2.5 t/ha Rice Straw + FNPK and 7.5 t/ha Rice Husk + V2 NPK (Figure 11) are attributed to higher growth rate and dry matter accumulation over other treatments as observed by Chan *et al.* (2007) that ear length increased when inorganic fertilizer was applied in integration with organic manure as compared to sole inorganic application. Similar observation was made by Uzoma *et al.* (2011) who observed that combination of organic and inorganic fertilizer enhanced maize ear characteristics due to incorporation of the organic material.

5.2.6 Cob Weight

Organic material sources in integration with inorganic fertilizer resulted in maximum cob weight compared to organic source alone and the control plants (Figure 12). The highest cob weight obtained in 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + V2 NPK, 5 t/ha Biochar + FNPK, 5 t/ha Biochar + V2 NPK, 7.5 t/ha Rice Straw + FNPK, 7.5 t/ha Rice Straw + V2 NPK, 7.5 t/ha Rice Husk + FNPK and 5 t/ha Rice Straw + FNPK applications is attributed to improved nitrogen uptake by maize through enhanced organic matter decomposition-mineralization process or indirectly maize root development. High nitrogen level and other nutrients obtained from the organic materials and inorganic fertilizer resulted in heavy cobs. Similar trend was observed by Khan *et al.* (2008) who detected that lower nitrogen level in the soil resulted in lighter grain weight due to less available nitrogen for the optimum plant growth. Also, the same results was obtained by Yadav *et al.* (2000) that integration of organic manure and inorganic fertilizer resulted in higher sustainable yield index compared with application of either alone.

5.2.7 Grain Yield

Grain yield is a function of the interaction among various yield components that were affected differentially by the growing conditions and crop management practices. Possible explanation for increase in grain yield in 7.5 t/ha Biochar + FNPK and 7.5 t/ha Biochar + Y2 NPK comparable to 7.5 t/ha Rice Husk + FNPK, 7.5 t/ha Rice Straw + FNPK, 2.5 t/ha Rice Husk + FNPK and 2.5 t/ha Biochar + FNPK (Figure 13) include the direct effect of organic materials on soil physio-chemical properties like enhance water holding capacity, increased cation exchange capacity (CEC), providing a medium for adsorption of plant nutrients and improved conditions for soil micro-organisms (Vanlauwe *et al.*, 2002; Saleque *et al.*, 2004; Sohi *et al.*, 2009). These results are in accordance with Singh *et al.* (2010) who observed that timely availability of nitrogen positively increased corn productivity through the combined use of organic manures and mineral fertilizer. The results are also in line with the work of Asai *et al.* (2009) who observed that integrated nitrogen strategies convincingly enhance corn yield attributes.

5.2.8 100 Seed Weight

Statistical analysis of the data showed that all treatment had significant effect on 100 grain weight. Heavier grains were observed with 7.5 t/ha Biochar + FNPK, 7.5 t/ha Biochar + Y2 NPK, 7.5 t/ha Rice Husk + FNPK, 2.5 t/ha Biochar + FNPK, 7.5 t/ha Rice Husk + Y2 NPK, 7.5 t/ha Rice Straw + FNPK and 7.5 t/ha Rice Straw + Y2 NPK applications are attributed to higher nitrogen level in the soil which resulted in heavier grain weight due to nitrogen availability for optimum maize growth and formation of assimilates for healthy grains (Khan *et al.*, 2008). The results are also confirmed by the findings of Asai *et al.* (2009)

who observed that integrated nitrogen strategies convincingly enhance corn yield attributes. Esse *et al.* (2001) also observed that application of smaller amounts of manure plus light fertilizer application was superior to inorganic fertilizer application alone.

5.2.9 Stover Weight

Statistical analysis of the data revealed that treatments had significant effect on stover weight. The increase in stover weight of maize observed in the application of BC3 + FNPK comparable to 7.5 t/ha Biochar + Y2 NPK, 7.5 t/ha Rice Husk + FNPK, 5 t/ha Biochar + Y2 NPK and 7.5 t/ha Rice Husk + FNPK was due to slow release and timely nitrogen availability from organic sources which were less subjected to lose. The combination of organic materials and inorganic fertilizer enhanced sufficient nutrients availability (mainly nitrogen), which resulted in increased dry matter accumulation. Similar result was reported by Uzoma *et al.* (2011) who observed that integrated nutrient management led to increased maize biomass production. Brouwer and Powell (1998) also observed that frequent smaller amounts of organic manure application plus light fertilizer application is superior to heavy fertilizer application alone.

5.2.10 Soil Physio-Chemical Analysis after Harvesting

Soil analysis at harvest indicated that the treatments enhanced soil physio-chemical properties over the control (Table 9). Organic matter improved the soil texture, increased organic carbon content and the major plant nutrients due to organic materials application. Masulili *et al.* (2010) observed an improvement of soil properties with organic soil amendment applications. Tualar *et al.* (2012) observed that the interaction between the application of organic fertilizers and inorganic fertilizers (nitrogen, phosphorus and potassium) affected organic carbon content and soil cation exchange capacity.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Pot Trial

This trial was carried out to determine the type of untreated indigenous organic material that best promotes maize productivity and how long should the materials be incorporated into the soil before planting. Parameters measured were days to emergence, plant height, leaf count and total dry matter production. Results showed that groundnut shell and biochar enhanced crop growth over rice straw, with rice husk being the least supportive.

At least 21 days of delay was required after the incorporation of the untreated organic materials for seed planting to maximise maize production.

It is therefore, recommended that resource poor farmers could utilize untreated groundnut shell and Biochar as organic fertilizers for effective crop production when incorporated into the soil 21 days before planting maize in the Guinea savannah zone of Ghana. Un-decomposed organic materials can also be used as manure in horticultural crops.

6.2 Field Trial

The experiment was conducted to determine the best organic material(s) that increase maize productivity in the Guinea savannah zone of Ghana. Parameters measured were plant height, leaf count, days to 50% flowering, height of cob attachment, cob length, cob weight, grain yield, 100 seed weight and stover weight. Results showed that 7.5 t/ha Biochar + V2 NPK, 7.5 t/ha Rice Husk + V2 NPK, 7.5 t/ha Groundnut Shells + V2 NPK, 7.5 t/ha Rice Straw + V2 NPK, 5 t/ha Biochar + V2 NPK, 5 t/ha Groundnut Shells + V2 NPK, 5 t/ha Rice Husk + V2 NPK and 5 t/ha Rice Straw + V2 NPK enhanced maize growth, yield and yield components over other treatments.

The treatments enhanced the soil physio-chemical properties after harvesting. The treatments influenced the soil pH, increased the organic carbon content and the major plant nutrient elements (nitrogen, phosphorus, potassium, calcium and magnesium) after harvesting.

It is therefore, recommended that resource poor farmers could utilize untreated organic materials alone at a rate of 5 to 7.5 t/ha to optimize maize production. Resource poor farmers can also untreated organic materials at a rate of 5 to 7.5 t/ha with 45-30-30 kg NPK/ha (half recommended NPK grade) as source of fertilizer to maximize maize production in the Guinea savannah zone of Ghana. Resource poor farmers should apply biochar at the rate of 5 to 7.5 t/ha with 45-30-30 kg NPK/ha to optimize maize yield in the Guinea savannah zone of Ghana. Resource poor farmers can also apply untreated organic materials such as ground shells, rice husk and rice straw at 5 to 7.5 t/ha with 45-30-30 kg NPK/ha as a fertilizer source to optimize maize productivity.

However, commercial farmer can utilize the untreated organic materials at the rate of 5 to 7.5 t/ha with 90-60-60 kg NPK/ha (full recommended NPK grade) to maximize maize productivity in the Guinea of savannah of Ghana.

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APPENDICES

Pot Trial

Appendix 1: Analysis of variance for Days to Emergence

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	2	2.6333	1.3167	6.79	
OM	3	9.2667	3.0889	15.93	<.001***
PD	4	11.4333	2.8583	14.74	<.001***
OM.PD	12	1.2333	0.1028	0.53	0.881ns
Residual	38	7.3667	0.1939		
Total	59	31.9333			

CV%=10.9; *** (Very highly Significant at *p<.001*); ns (not significant) NB: OM = Organic materials, PD = Planting Date.

Appendix 2: Analysis of variance for Leaf Count @ 2WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	2	0.030243	0.015122	2.80	
OM	3	0.114513	0.038171	7.07	<.001***
PD	4	0.140477	0.035119	6.51	<.001***
OM.PD	12	0.035737	0.002978	0.55	0.866ns
Residual	38	0.205023	0.005395		

Total	59	0.525993

CV%=3.6; *** (Very highly Significant at $p < .001$); ns (not significant) NB: OM =

Organic materials, PD = Planting Date.

Appendix 3: Analysis of variance for Leaf count @3WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	2	0.104053	0.052027	6.01	
OM	3	1.005833	0.335278	38.73	<.001***
PD	4	0.209640	0.052410	6.05	<.001***
OM.PD	12	0.144400	0.012033	1.39	0.213ns
Residual	38	0.328947	0.008656		
Total	59	1.792873			

CV%=4.1; *** (Very highly Significant at *p<.001*); ns (not significant) NB: OM = Organic materials, PD = Planting Date.

Appendix 4: Analysis of variance for Leaf Count @4WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	2	0.10477	0.05238	2.99	
OM	3	1.32425	0.44142	25.17	<.001***
PD	4	0.17201	0.04300	2.45	0.062*
OM.PD	12	0.06154	0.00513	0.29	0.987ns
Residual	38	0.66650	0.01754		
Total	59	2.32906			

CV%=5.6; *** (Very highly Significant at *p<.001*), * (Significant); ns (not significant) NB:

OM = Organic materials, PD = Planting Date.

Appendix 5: Analysis of variance for Leaf Count @5WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	2	0.00252	0.00126	0.06	
OM	3	0.85497	0.28499	12.90	<.001***
PD	4	0.27460	0.06865	3.11	0.026*
OM.PD	12	0.22833	0.01903	0.86	0.590ns
Residual	38	0.83928	0.02209		
Total	59	2.19970			

CV%=6.1; *** (Very highly Significant at *p<.001*) * (Significant); ns (not significant) NB: OM = Organic materials, PD = Planting Date.

Appendix 6: Analysis of variance for Leaf Count @6WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	2	0.02892	0.01446	0.82	
OM	3	2.38914	0.79638	45.18	<.001***
PD	4	0.19122	0.04781	2.71	0.044*
OM.PD	12	0.08144	0.00679	0.39	0.961ns
Residual	38	0.66981	0.01763		
Total	59	3.36054			

CV%=5.3; *** (Very highly Significant at *p<.001*) * (Significant); ns (not significant) NB: OM = Organic materials, PD = Planting Date.

Appendix 7: Analysis for variance for Plant Height @2WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	2	3.70	1.85	0.13	
OM	3	686.26	228.75	15.86	<.001***
PD	4	1895.17	473.79	32.85	<.001***
OM.PD	12	118.45	9.87	0.68	0.755ns
Residual	38	548.03	14.42		
Total	59	3251.60			

CV%=10.8; *** (Very highly Significant at *p<.001*); ns (not significant) NB: OM = Organic materials, PD = Planting Date.

Appendix 8: Analysis of variance for Plant Height @3WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	2	46.61	23.31	1.13	
OM	3	642.00	214.00	10.38	<.001***
PD	4	226.44	56.61	2.75	0.042*
OM.PD	12	268.58	22.38	1.09	0.399ns
Residual	38	783.59	20.62		
Total	59	1967.22			

CV%=9.5; *** (Very highly Significant at *p<.001*), * (Significant); ns (not significant) NB: OM = Organic materials, PD = Planting Date.

Appendix 9: Analysis of variance for Plant Height @4WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	2	87.27	43.63	1.23	
OM	3	1785.77	595.26	16.73	<.001***
PD	4	1079.12	269.78	7.58	<.001***
OM.PD	12	182.46	15.20	0.43	0.943ns
Residual	38	1352.21	35.58		
Total	59	4486.81			

CV%=10.6; *** (Very highly Significant at *p<.001*); ns (not significant) NB: OM = Organic materials, PD = Planting Date.

Appendix 10: Analysis of variance for Plant Height @5WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	2	236.36	118.18	1.82	
OM	3	3016.87	1005.62	15.48	<.001***
PD	4	499.71	124.93	1.92	0.126ns
OM.PD	12	396.84	33.07	0.51	0.896ns
Residual	38	2468.16	64.95		
Total	59	6617.93			

CV%=12.4; *** (Very highly Significant at *p<.001*); ns (not significant) NB: OM = Organic materials, PD = Planting Date.

Appendix 11: Analysis of variance for Plant Height @6WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean of Squares	F. Tab.	F. Prob.
REP stratum	2	310.03	155.02	4.90	
OM	3	3049.06	1016.35	32.15	<.001***
PD	4	927.71	231.93	7.34	<.001***
OM.PD	12	371.03	30.92	0.98	0.486ns
Residual	38	1201.28	31.61		
Total	59	5859.11			

CV%=7.9; *** (Very highly Significant at *p<.001*); ns (not significant) NB: OM = Organic materials, PD = Planting Date.

Appendix 12 : Analysis of variance for Total Dry Matter

Source of Variation	Degree of Freedom	Sum of Squares	Mean of Squares	F. Tab.	F. Prob.
REP stratum	2	461.09	230.55	5.61	
OM	3	1391.21	463.74	11.29	<.001***
PD	4	1076.37	269.09	6.55	<.001***
OM.PD	12	607.46	50.62	1.23	0.298ns
Residual	38	1560.90	41.08		
Total	59	5097.04			

CV%=33.3; *** (Very highly Significant at *p<.001*); ns (not significant) NB: OM =

Organic materials, PD = Planting Date.

Field Trial

Appendix 13: Analysis of variance for Plant Height@9WAP.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	3	2703.44	901.15	9.09	
TRT	36	9066.48	251.85	2.54	<.001***
Residual	108	10701.71	99.09		
Total	147	22471.63			

CV%=5.3; *** (Very Highly Significant at $p<.001$). NB: TRT = Treatments

Appendix 14: Analysis of variance for Leaf Count@9WAP.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. prob.
REP stratum	3	0.120545	0.040182	7.92	
TRT	36	0.281487	0.007819	1.54	0.046*
Residual	108	0.548199	0.005076		
Total	147	0.950231			

CV%=2.1; * (Significant at $p=0.046$). NB: TRT = Treatments

Appendix 15: Analysis of variance for Days to 50% Flowering.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	3	117.054	39.018	16.27	
TRT	36	315.108	8.753	3.65	<.001***
Residual	108	258.946	2.398		
Total	147	691.108			

CV%=2.9; *** (Very Highly Significant at *p<.001*). NB: TRT = Treatments

Appendix 16: Analysis of variance For Height of Cob Attachment.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	3	2516.03	838.68	24.38	
TRT	36	6640.17	184.45	5.36	<.001***
Residual	108	3715.32	34.40		
Total	147	12871.52			

CV%=7.9; *** (Very Highly Significant at *p<.001*). NB: TRT = Treatments

Appendix 17: Analysis of variance For Cob Length.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	3	19.945	6.648	5.68	
TRT	36	149.668	4.157	3.55	<.001***
Residual	108	126.309	1.170		
Total	147	295.923			

CV%=7.0; *** (Very Highly Significant at $p<.001$). NB: TRT = Treatments

Appendix 18: Analysis of variance for Cob Weight.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab.	F. Prob.
REP stratum	3	30311.8	10103.9	29.52	
TRT	36	63287.7	1758.0	5.14	<.001***
Residual	108	36969.1	342.3		
Total	147	130568.6			

CV%=16.0; *** (Very Highly Significant at $p<.001$). NB: TRT = Treatments

Appendix 19: Analysis of variance For Grain Yield.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab	F. Prob.
REP stratum	3	43.4960	14.4987	33.08	
TRT	36	89.2665	2.4796	5.66	<.001***
Residual	108	47.3349	0.4383		
Total	147	180.0974			

CV%=15.1; *** (Very Highly Significant at *p<.001*). NB: TRT = Treatments

Appendix 20: Analysis of variance For 100 Seed Weight.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab	F. Prob.
REP stratum	3	486.385	162.128	25.50	
TRT	36	553.153	15.365	2.42	<.001***
Residual	108	686.795	6.359		
Total	147	1726.333			

CV%=9.7; *** (Very Highly Significant at *p<.001*). NB: TRT = Treatments

Appendix 21: Analysis of variance For Stover Weight.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F. Tab	F. prob.
REP stratum	3	5.8082	1.9361	17.21	
TRT	36	45.8777	1.2744	11.33	<.001***
Residual	108	12.1462	0.1125		
Total	147	63.8321			

CV%=9.6; *** (Very Highly Significant at $p<.001$). NB: TRT = Treatments