KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

FACULTY OF RENEWABLE NATURAL RESOURCES

DEPARTMENT OF AGROFORESTRY

EFFECTS OF BIOCHAR AND INORGANIC FERTILIZER APPLICATION ON SOIL FERTILITY AND AGRONOMIC PERFORMANCE OF MAIZE

(*Zea mays*)

EUNICE BADU

SEPTEMBER, 2016

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A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES,

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BACHELOR OF SCIENCE (NATURAL RESOURCE MANAGEMENT)

SEPTEMBER, 2016

DECLARATION

I hereby declare that, except references to other people‘s work which have been duly cited, this work submitted as a thesis to The Department of Agroforestry, Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, for the degree of Master of Philosophy in Agroforestry, is a result of my own investigation, and that it has, neither in whole nor in part, been submitted elsewhere for another degree.

EUNICE BADU ……………………… ………...............

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Certified by:

DR. AKWASI A. ABUNYEWA ……………………… ………...............

(HEAD OF DEPARTMENT) SIGNATURE DATE

DEDICATION

I dedicate this thesis to:

The Lord Almighty for being the stronghold of my life and the source of my academic excellence, my husband Edwin Agyabeng-Dadzie and my lovely twin boys Kirk and Klaus Agyabeng-Dadzie.

ABSTRACT

Biochar application on agricultural soils could provide a new technology for both soil fertility and crop productivity improvement. Meanwhile, limited research has investigated the suitability of biochar for soil improvement practices in Ghana. The aim of this research was to determine the synergistic effect of biochar and inorganic N fertilizer on soil fertility improvement and crop performance. The research was conducted at the Faculty of Renewable Natural Resources Research farm in the minor and major cropping seasons of 2012 and 2013 respectively. Biochar was applied at 0, 5, 10, 15 and 20 t ha^{-1} and fertilizer N applied at 0, 45 and 90 kg ha^{-1}. The results of this study demonstrated that the application of fertilizer N may improve soil fertility and increase the biological yield of maize but their effects may be higher when applied with biochar (particularly at 10 t ha^{-1}). Relative to the control, the application of biochar at 10 t ha^{-1} increased grain yield by 213% and 160% in the minor and major cropping seasons respectively. The greater yield of maize recorded on biocharamended soils was attributed to the improved nutrient uptake and nitrogen use efficiency. The results showed that biochar application increased N uptake by about 200% compared with un-amended plots. In conclusion, the results of this study points to the fact that biochar could be an important resource for resource-poor farmers within the study area.

Keywords: biochar; fertilizer; soil fertility; crop production

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―At times our own light goes out and is rekindled by a spark from another person. Each of us has cause to think with deep gratitude of those who have lighted the flame within us"… Albert Schweitzer

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CHAPTER ONE

INTRODUCTION

In sub-Saharan Africa, decline in soil productivity due to continuous cropping coupled with rapid organic matter mineralization are the main causes of food insecurity and poverty (Moses et al., 2011). The situation has resulted in many countries being classified as land-scarce (Binswanger and Pingali, 1988). Yield increase per unit area, rather than area expansion, will thus become progressively more important as a means of increasing crop production (Heisey and Mwangi, 1996). Crop production from these soils is low and there is continuous decline in soil fertility. The need to address these soil fertility problems aimed at achieving high crop yields as well as ensuring food security has become urgent (Yeboah et al., 2009). The success of any growing media for plants relies critically on its management. This involves maintaining an appropriate soil organic matter and nutrient cycling. Over the years, the use of practices such as shifting cultivation due to abundance of land is gradually being abolished due to the ever increasing population growth. This has led to the introduction of the use of cover crops, mulches, compost, or manure additions which again offer an effective means for supplying nutrients to crops, supporting rapid nutrient cycling through decomposition and mineralization, and helping to retain applied mineral fertilizers better (Trujillo, 2002). The benefits of such amendments are however short lived (Jenkinson and Ayanaba, 1977) due to high decomposition rates and subsequent mineralization of added organic matter within a few cropping seasons (Bol et al., 2000; Diels et al., 2004; Tiessen et al., 1994). The quality of organic inputs in terms of nitrogen, lignin and polyphenols has been suggested to influence the decomposition of organic inputs (Palm et al., 2001). The decomposition of organic resources releases gases such as CO_2, methane, N_2O which are greenhouse gases and are of global concerns for climate change. Alternatively, the application of inorganic fertilizers provide an option to overcome soil infertility, but again, the removal of subsidies on fertilizers has rendered this option inaccessible by smallholder farmers (Garrity, 2004). The transportation of the fertilizers to farmer‘s fields is a major problem as farmers‘ fields are generally far from the homestead (Yeboah et al., 2009). Despite some of the setbacks in using these nutrient management strategies, the use of both organic and inorganic fertilizers have offered a lot of contribution in the maintenance of soil fertility.

Generally, most of the soils in the country are formed on extremely weathered parent materials, highly leached, mostly eroded and often common to all the agro-ecological zones. The average fertility status of soils of the different regions is characterized by low levels of organic carbon, nitrogen and available phosphorus with potassium being mostly abundant in the soils of Ghana (FAO, 2003). Evaluating these facts from FAO depicts the high urgency and need to address soil management strategies aimed at improving the relatively low fertility of soils in Ghana. One of such newly introduced soil management techniques is the use of biochar as a soil amendment.

Biochar is a highly aromatic form of organic matter that is present in most soils to varying extents (Schmidt and Noack, 2000). It is produced with the intent to deliberately apply to soils to sequester carbon (Sombroek et al., 2003) and improve soil properties (Lehmann and Joseph, 2009). Biochar-based soil management strategies in Ghana are new and have not been evaluated in the context of the country‘s agricultural system (Moses et al., 2011). It‘s incorporation in soils has mostly been carried out within the context of research and testing. Only a few farmers in the country have applied biochar to agricultural soils even though they are present in most soil to varying extents. Biochar may occur naturally in soil as a consequence of wildfire. This is evident even in a simple slash and burn activity on the farm. According to Yeboah et al. (2009) rotational slash and char system practiced in some agricultural margins of the country is known to double crop yields. However, the application of biochar in the country‘s farming systems has become imperative. This may due to the ever increasing pressure on land stemming from increased population coupled with declining land availability and declining soil fertility. Biochar application on agricultural soils could provide a new technology for both soil fertility and crop productivity improvement, with potential positive and quantifiable environmental benefits, such as carbon trading (Bracmort, 2010).

Biochar amendment to soils over the past few years has been projected as an effective soil management option that could help overcome soil fertility management challenges. The effects of biochar depend on the soil fertility and the water balance at a given site, and possibly even the cultivated genotype (Asai et al., 2009). As such, varied outcomes with regard to the effects of biochar application on soils have been reported. According to Lehmann et al. (2002), biochar application could temporarily limit soil N availability in N deficient soils due to their high C/N ratio and therefore reducing crop productivity. It must however be noted that most of these studies focused on the sole use of biochar with limited information on the combined effects of both fertilizer and biochar.

According to De Gryze et al. (2010) and Quayle (2010), the combined application of biochar and inorganic fertilizer has the potential to increase crop productivity, thus providing additional incomes, and reducing the quantity of inorganic fertilizer use and the quantity of inorganic fertilizer imported. Steiner et al. (2007), also reported that application rate of 5 t/ha of biochar decreased fertilizer needs by 7%.

Hence the need to answer some fundamental questions on biochar and fertilizer interaction and nutrient use efficiency is important. Having knowledge about these major component interactions will be much beneficial in terms of enhancing soil nutrient availability and improving food production trends. The study will provide valuable information on biochar use as a soil management strategy which is relatively new in Ghanaian cropping systems. This can be achieved through the evaluation of the effect of biochar amendment with different nitrogen application rates on nitrogen use efficiency in the moist semi deciduous forest zone of Ghana.

Specifically, this research quantified and compared the effects of adding biochar and conventional inorganic N fertilizers on:

i. Some soil chemical properties (CEC, pH, Mineral N)
ii. Maize N uptake and N use efficiency
iii. Grain and stover yield of maize

1.1 Hypotheses

The study is based on the following hypothesis:

Biochar with or without inorganic N fertilizer application would significantly increase maize grain yield, N uptake, and N use efficiency.

CHAPTER TWO

LITERATURE REVIEW

2.1 Biochar

Biochar is commonly defined as charred organic matter that is produced with the intent to deliberately apply to soils to sequester carbon (Sombroek et al., 1993) and to improve soil properties (Lehmann and Joseph, 2009). It is a term reserved for the plant biomass derived materials contained within the black carbon continuum. This definition includes chars but charcoal excludes fossil fuel products or geogenic carbon (Lehmann et al., 2006). Biochar is produced by partially combusting (charring) carbonaceous source materials, e.g. plant tissues (Schmidt and Noack, 2000; Preston and Schmidt, 2006; Knicker, 2007), with both natural as well as anthropogenic sources. It is a fine-grained and porous substance, comparable in its appearance to charcoal produced by natural burning. The only difference between biochar and charcoal is in its utilitarian intention; charcoal may be produced for other reasons (e.g. heating, barbeque, etc.). Biochar and charcoal appear to be essentially the same material in a physicochemical sense. Thus for the purpose of soil science, biochar can be defined differently as biomass that has been pyrolysed in a zero or low oxygen environment that due to its inherent properties may specifically be applied to a site to purposely sequester carbon and synchronously improve soil functions while avoiding short- and long-term detrimental effects to the wider environment (Sohi et al., 2009).

2.1.1 Biochar Production

There are various types of biomass resources that can be used in the production of biochar. In Ghana, it ranges from agricultural crop residues and by products, forestry residues and manures (Moses et al., 2011). Biochar production and utilization systems (BPUS) entail three components: (1) feedstock acquisition and preparation, (2) feedstock conversion, and (3) biochar handling, transport, and application. There appears to be several combinations of feedstocks, production technologies, and application systems; especially that may be aimed at promoting a particular system (Madison, 2010).

2.1.2 Feedstocks for Biochar Production

Feedstock is the term used for the type of biomass that is pyrolysed and turned into biochar (Verheijen et al., 2010). Several feedstocks have been used over the years in biochar production, including grain husks, nut shells, wood, manure, crop residues and even the most common wastes made in our homes. Some of these feedstocks have varied carbon contents, abundancy rates and lower associated costs which are greatly considered in the production of activated carbon (Martinez et al., 2006; Gonzaléz et al., 2009). Other potential feedstocks available for biochar production, such as biowaste and compost pose a risk, mostly linked to the occurrence of hazardous components. Of all these feedstocks, wood chip and wood pellets, tree bark, crop residues, switch grass, organic wastes including distillers grain, bagasse from the sugarcane industry and olive waste (Yaman, 2004), chicken litter (Das et al., 2008), dairy manure, sewage sludge (Shinogi et al., 2002) and paper sludge are currently used at a commercial-scale or in research.

Annually the production of agricultural residues is estimated to be more than 500 million tonnes (Sanchez, 2009). Presently in Ghana, forest resources provide as a major source of biomass which can contribute considerably to biochar production. In 2006, estimates provided by the Food and Agriculture Organization (FAO) of the United Nations indicated that the total forest area covered roughly 5.52 million ha, approximately 24.3% of the total land area (FAO, 2009). This represented a considerably large portion of the total land in Ghana with forest plantations in the country covering about 76,000 ha in 2000 (Zhang, 2007). Forestry residues can be put into two categories: (i) logging residues and (ii) wood processing wastes

Sawmill residues are among the most promising feedstock for bioenergy production (Sekyere, 2007). The actual quantity of wood waste generated varies with tree species, the type of operation and maintenance of the plant (Parikka, 2004). Clearly, the utilization of wood processing wastes as feedstock for bioenergy or biochar production could be attractive since they are normally abundant at the various mills, thus easing their collection.

Apart from secondary residues such as discarded logs, bark, sawdust, and off-cuts generated through sawmill and plywood mill, logging residues including stumps, offcuts, branches, thinning, twigs and saw dust are used and are referred to as primary residues. It is estimated that 720,000 m^3, equivalent to 360,000 tonnes of logging residues were generated in Ghana in 2008 (Duku et al., 2011). According to (Parikka, 2004), less than 66% of the volume of woody biomass is generally removed from the forest for further processing, while the remaining quantity is either left on-site, burnt on-site or utilized as wood fuel. However, a study by Amoah and Becker (2009) on commercial logging efficiency in Ghana showed an average logging recovery of 75%. Even though logging residues may appear to be an attractive feedstock for biochar production, they are however widely dispersed and not all these residues could be used for either bioenergy or biochar production. For instance, leaving appropriate levels of logging residues in the forest protects soil quality and further eliminates the need for fertilizers (Duku et al., 2011).

The type of feedstock together with the pyrolysis conditions greatly determines the properties of the resulting biochar. According to Verheijen et al. (2010), the chemical and structural composition of the biomass feedstock relates to the chemical and structural composition of the resulting biochar and, this is highly being reflected in its function, behaviour and fate in soils. This is confirmed in De Gryze, 2010 that chemical properties of the feedstock have a significant influence on both the yield and quality of the produced biochar and the decomposability of biochar will be dependent on the chemical nature of the initial feedstock (Nguyen and Lehmann, 2009; Zimmerman, 2010). The extent of the physical and chemical alterations undergone by the biomass during pyrolysis (e.g. attrition, cracking, microstructural rearrangements) is dependent on the processing conditions. Moses et al. (2011) again states that the structure of any given biochar reflects the morphological characteristics of the feedstock. Similarly, the composition, quality and characteristics of biochar such as density, particle size distribution, ash content, moisture content and pH depend on the type, nature and origin of the feedstock, together with pyrolysis reaction conditions (Zhang, 2007).

2.1.3 Feedstock Pyrolysis

Pyrolysis is the chemical decomposition of an organic substance by heating in the absence of oxygen. It is practically impossible to create a completely oxygen free environment and thus a small amount of oxidation will always occur. Yet, the degree of oxidation of the organic matter is relatively small when compared to combustion where there is almost a complete oxidation of organic matter, and as such a substantively larger proportion of the carbon in the feedstock remains and is not given off as CO_2 (Verheijen, 2010). There are three different resulting components of the pyrolysis transformation process of organic materials and these are gas, liquid or solid in different proportions depending upon both the feedstock and the pyrolysis conditions used. Gases which are produced include methane and other hydrocarbons which can be cooled whereby they condense and form an oil/tar residue which generally contains small amounts of water. These gases either condensed or in gaseous form as well as liquids can be upgraded and used as a fuel for combustion. The remaining solid component apart from these gases and liquids after pyrolysis is charcoal. This is referred to as biochar when it is produced with the intention of adding it to soil to improve it.

Biochar Pyrolysis of feedstocks into biochar can be classified into three main groups, namely slow, intermediate and fast (McLaughlin, 2010; Brown, 2009). Depending on the temperatures reached during combustion and the species identity of the source material, chemical and physical properties of biochar may vary (Keech et al., 2005; Gundale and DeLuca, 2006). Coniferous biochar generated at lower temperatures, e.g. 350°C, can contain larger amounts of available nutrients than biochar generated at higher temperatures (e.g. 800°C) (Gundale and DeLuca, 2006). Table 2.1 shows that different pyrolysis conditions lead to different proportions of each end product (liquid, char or gas). These specific types of pyrolysis conditions can however be tailored to each desired outcome. Nonetheless, considering the use of biochar as a soil amendment and for climate change mitigation it is clear that slow pyrolysis, would be preferable, as this maximizes the yield of char.

Table 2.1: Typical product yields (dry wood basis) obtained by different modes of pyrolysis of wood (De Gryze et al., 2010).

Mode	Condition	Liquid(bio-oil)	Solid(biochar)	Gas(syngas)
Fast pyrolysis	Moderate temperature(~500 ^{0}c) Short vapour residence time	75% (25%water)	12%	13%

Intermediate pyrolysis	Low-moderate temperature. Moderate hot vapour residence time	50% (50% water)	25%	25%
Slow pyrolysis	Low-moderate temperature. Long residence time	30% (70% water)	35%	35%

Slow pyrolysis involves the thermal conversion of biomass by slow heating at low to medium temperatures (450 to 650°C) in the absence of oxygen, with the simultaneous capture of syngas. Usually feedstocks in a form of dried biomass pellets characterized by various particle sizes are fed into a heated furnace and exposed to uniform heating. This process conditions consist of long vapour residence times more than around 10s, reactor temperatures between 450 and 650˚C, reactor operating at atmospheric pressure and very low heating rates which range from 0.01 to 2.0˚C. These conditions result in increased cracking reactions that reduce the liquid organic yield and consequently increase the biochar yield (Sohi et al., 2009).

Fast pyrolysis involves a very rapid feedstock heating which leads to a much greater proportion of bio-oil and less biochar. It is primarily aimed at achieving high yield of liquid. In the case of slow pyrolysis, the time taken to reach peak temperature of the endothermic process is approximately one or two seconds, rather than minutes or hours. The lower operating temperature also enhances the overall conversion efficiency of the process relative to slow pyrolysis (Sohi et al., 2009).

Intermediate pyrolysis describes a hybrid technology, designed to produce bio-oil with very low tar content. The process has been tested with woody and non-woody feedstocks. This pyrolysis method produces biochar in greater quantity as compared to fast pyrolysis (Sohi et al., 2009).

It can therefore be concluded that, fast pyrolysis generates higher liquid yields while slow pyrolysis and intermediate pyrolysis both result in higher biochar yields. Thus, to optimize the production of biochar, slow pyrolysis and intermediate pyrolysis seem to be the most appropriate technology choice. Pyrolysis conditions which favour high biochar yields are: (i) high lignin, ash and nitrogen contents in the biomass, (ii) low pyrolysis temperature (<400˚C), (iii) high process pressure, (iv) long vapour residence time, (v) extended vapour/solid contact, (vi) low heating rate, (vii) large biomass particle size, and (viii) optimized heat integration (Moses et al., 2011).

2.1.4 Biochar Application Methods

Biochar can be applied in several ways. Broadly speaking there are three main approaches: i) topsoil incorporation, ii) depth application, and iii) top-dressing (Verheijen et al., 2009). Other widely used methods include mixing with fertilizer and seed, applying through no till systems, uniform soil mixing, deep banding with plow, top-dressed, hoeing into the ground, applying compost and char on raised beds, and spreading around farms to capture run off. The type of application of biochar in soil can however be influenced by the farming system used, available machinery and labour (Moses et al., 2011). The effectiveness of biochar application, however, depends on the method of application (Schmidt and Noack, 2000; De Gryze et al., 2010). This can be attributed to its proper interaction with the soil to obtain maximum outcome. Biochar is applied beneath the soil surface to a depth which ranges from 0.1 to 0.2 m in the deep banding applications. According to De Gryze et al. (2010), apart from eliminating dust, this method of biochar application in soil also creates both good soil–biochar and plant–

biochar contact. This method of the biochar application directly into the rhizosphere is thought to be more beneficial for crop growth and less susceptible to erosion. In top-dressed biochar applications, biochar is added to the soil surface. This mode of application can also cause environmental hazards when care is not taken so far as particle size of biochar is concerned. Due to the low density of biochar, wind or even water may cause biochar to be eroded since it is usually incorporated between 0-15/30 cm depths of the soil. There is still much to be investigated on the effect of biochar application strategy on soil compaction while focusing on the risk of erosion by water and wind, as well as human health and impacts on other ecosystem components (Verheijen et al., 2009).

2.1.5 Why Biochar?

2.1.5.1 Carbon Sequestration

Climate change remains widely recognized as a serious threat facing the modern world. One major concern is global warming which has significant impact on agriculture and food production sectors and consequently on food security; and as such, the concept and value of biochar production and application is gradually incorporated by policy makers and governments (Winsley, 2007). Temperature increases have now been undeniably proven and are occurring with an unprecedented rate (IPCC, 2001). There are important drivers of the anthropogenic greenhouse effect such as Carbon dioxide (CO_2), methane (CH_4) and nitrous oxides which are released both through burning of fossil and biomass fuel as well as decomposition of above and below ground organic matter. Several efforts have been made in the international front to curb the problem of climate change through reduction of avoidable greenhouse gas emissions and or off-setting unavoidable emissions through sequestration of carbon in the environment. Both long term and short term strategies have been adopted ranging from wide-spread afforestation and reforestation in terrestrial ecosystems (IPCC, 2000) to pumping of CO_2 into deep ocean and geological layers (Marchetti, 1977; DOE, 1999). One such new technique gaining high potential of carbon sequestration is by increasing soil carbon stocks (Batjes, 1998; Izaurralde et al., 2001; Scholes and Noble, 2001) with soil acting as a much stable carbon sink.

There are two main ways that biochar influences the global carbon cycle. One influential way is that, biochar is normally produced from material that would otherwise oxidize in the short to medium term with the resultant carbon-rich char being placed in an environment which is protected from oxidation. This provides a means to sequester carbon which in turn is prevented from entering the atmosphere as a greenhouse gas. Gaseous and liquid products of pyrolysis may also be used as a fuel that can offset the use of fossil fuels (Woolf, 2008).

As much emphasis is being dealt on biochar and its potential for sequesting carbon, some authors (Lehmann, 2006) have used biochar as a soil amendment in different researches and met the requirements specified above that the char sequesters carbon. Again detailed reviews on carbon dynamics (Preston et al., 2006; Czimczik et al., 2007), and its consequent role in the global carbon cycle (Schmidt et al., 2000) are still developing. This guarantees biochar to be recalcitrant to degradation (Baldock and Smernik, 2002) and regarded as being much stable in the soil. Globally, soil is estimated to hold more organic carbon (1,100 Gt) than the atmosphere (750 Gt) and the terrestrial biosphere (560 Gt) (Post et al., 1990; Sundquist, 1993). The net benefit of using biochar in terms of mitigating global warming and as an active strategy to manage soil health and productivity have been emphasized by quite a number of studies (Lehmann, 2007a;

Lehmann, 2007b; Lehmann et al., 2005; Laird, 2008; Ogawa et al., 2006; Woolf, 2008; Mathews, 2008). However, relatively few studies exist that make a quantitative valuation of biochar-based soil management scenarios with regard to greenhouse energy, gas and economic perspectives (Fowles, 2007; Gaunt et al., 2008).

Bracmort (2010) attributes cropland soils and grazing lands as two of the major agricultural source of N_2O emission and biochar application to the soil can lower GHG emissions of cropland soils by substantially reducing the release of N_2O (Lehmnan, 2007). N_2O and CH_4 emission reductions through biochar application has been seen to gain substantial attention due to the much higher global warming potentials of these gases compared to CO_2 (Steiner, 2010). In the Eastern Colombian Plains Rondon et al. (2005) reported in a study that there was a 50% reduction in N_2O emissions from soybean plots and almost complete suppression of CH_4 emissions from biochar amended acidic soils. Again there was a reduction of 85% in N_2O emission of re-wetted soils containing 10% biochar, compared to soils without biochar as cited in Steiner, (2010) and this was reported by Yanai et al. (2007). This was no different from a report by Spokas et al. (2009) who also found an 85% reduction in N_2O emission amounting to a significant reduction in N_2O emission in agricultural soils in Minnesota, while Sohi et al. (2009) found an emission suppression of only 15%.

Several factors must be considered in order to evaluate the carbon sequestration potential of adding biochar to soil. They include the longevity of char in soil; the avoided rate of greenhouse gas emission; how much biochar can be added to soils; and how much biochar can be produced by economically and environmentally acceptable means (Woolf, 2008). Biochar must be long- lived and resistant to the process of oxidation into CO_2 in the soil to attain its long term effect of sequestering carbon in the soil. Herring (1985) found out in a study of marine sediments in the North Pacific Basin that ―charcoal in the marine sediment is stable for several tens of millions of years‖ and that ―charcoal forms a large percentage of the carbon content in the sediments‖. Forbes et al. (2006); Glaser et al. (2001); Saldarriaga, et al. (1986) also reported that large stocks of charred material with residence times in excess of 1000 years have also been found in soil profiles. There is no doubt that studies from the meridian Amazonian dark earth several hundred years after the cessation of activities accumulated large stocks of pyrogenic black carbon (Glaser et al., 2003) confirming its longevity. These observations do not, however, rule out the possibility that char may decompose more rapidly in other environments. Indeed there is evidence that it may do so. Siberian boreal forest fires give evidence for the probable presence of an unknown process for removing biochar fairly rapidly from soil. It was found out by Czimczik et al. (2003) that, little biochar remained just 250 years after a forest fire compared to the amount that might be expected to have been produced. This offers a number of hypotheses to explain this. Either there could have been biochar losses through erosion or probably a low conversion of organic carbon to biochar in the fire; translocation within the soil profile and degradation (Woolf, 2008).

Two possible mechanisms for this suggested by Czimczik et al., (2003) are oxidation by subsequent fires or by microbial action.

There seems to be no definite market price available for carbon sequestration. If these prices could be made known to a farmer with a clear indication of its importance, then farmers will be able to appreciate the need to sequester carbon in stable sinks such as the soil. Maybe this is easier said than because the positioning of climate change solution through biochar is premature and more experiments are yet to be conducted.

Lehmann and Joseph (2009) and Verhejien et al. (2010) specify that biochar production under a controlled system may provide a higher yield and have fewer detrimental effects on the environment. Scientifically, there is the hope that biochar can contribute to climate change solution but let us not rule out the fact that it could even worsen climate change and pose health problems for people under uncontrolled systems.

2.1.5.2 Soil Fertility Improvement

Soil fertility is a measure of the ability of soil to sustain satisfactory crop growth in the long-term, and can be determined by physical, chemical and biological processes intrinsically linked to soil organic matter content and quality. Considering a decline in soil fertility is a major constraint to food productivity, investing in practices leading to soil fertility enhancement is likely to generate large returns (Syers, 1997). For thousands of years, biochar has been used as a fertility amendment in soils of tropical regions although scientific investigations of the effects on soil fertility are few but developing (Novak et al., 2009). One main interest is the agronomic benefits it may provide (Quayle, 2010). This may not be achieved directly but through the improvement of soil physical, chemical and biological properties the overall crop yield of a system is improved.

(a) Influence of biochar on soil properties

Soil types vary from one agroecological zone to the other and this is highly connected to the fertility of the soil. The differences in the inherent quality of soils are determined by age, parent material, physiography, and climatic conditions and this may clearly be linked to how fertile the soil may be. Entisols have low water holding capacity and nutrient content, are weakly structured, and are prone to erosion. Alfisols have a clay accumulation horizon, low capacity to store plant nutrients, and tend to acidify under continuous cultivation. Vertisols have a high content of swelling clays and low phosphorus (P) availability. Soils in semiarid Africa are generally low in organic carbon and total nitrogen (N) because of low biomass production and a high rate of decomposition (Mokwunye et al., 1996). These characteristics indicate how nutrient management could be approached, for example, the P requirement for maximum yield on soils in the semiarid areas is often low (Mokwunye, 1979) because they contain low-activity clays and consequently low capacity to occlude added P. The sandy structure presents problems of efficient use of applied N because of high rates of loss through leaching. In subhumid and humid Sub Saharan Africa (SSA), the dominant soils are Alfisols, Ultisols (Nitisols), and Oxisols (Ferralsols). Ultisols and Oxisols have little or no weatherable minerals. Bationo et al. (2006) suggested that the different dominant soils within agroecological zones of SSA demonstrate representative trends in moisture and nutrient storage capacity, organic matter content and nutrient depletion.

Generally positive effects of biochar have been reported on soil quality and crop productivity but vary form one condition to another. Most of these experiments conducted in the fields between 1980 and 2009 were carried out in soils of low fertility, including acidic tropical soils. Several authors noticed a greater effect of biochar in poorer than more fertile soils. Long-term positive effects of biochar applications were observed in few studies which were monitored over several years (Blackwell et al., 2009; Major et al., 2010b; Steiner et al., 2007). Though little might have been found on the effect of biochar on physical properties with a generalized understanding of the mechanism responsible for the few benefits known, there seem to be appreciable benefits.

Depending on the type of soil in an agroecological area, properties such as structure, texture, pore size distribution and density with implications for soil aeration, water holding capacity and soil nutrient retention leading to an enhancement of plant growth are mostly improved (Downie et al., 2009; Glaser et al., 2002; Lehmann et al., 2003; Lehmann and Rondon 2005; Sohi et al., 2009). Biochar has a much lower bulk density (~0.3 Mgm^{-3}) than that of mineral soils (1.39 Mgm^{-3}) (Brady & Weil, 2004), and therefore biochar application can reduce the overall total bulk density of the soil. Biochar with low mechanical strength can however increase the bulk density of the soil when they disintegrate quickly into small particles and fill up the existing pore spaces in the soil (Verheijen et al., 2010).

Incorporation of larger particles biochar may result in increased aeration of the soil and reduces anoxic microsites. This influences various soil processes such as decomposition rates of organic matter, nitrification - denitrification dynamics, and

GHG‘s emissions. Fine particle biochar particles may fill existing soil pores and thus potentially compact the soil and increase soil density.

(b) Influence of biochar on soil PH and CEC

Biochar has the potential to increase soil pH (Chan et al., 2007; Novak et al., 2009; Laird et al., 2010; Van Zwieten et al., 2010a; Peng et al., 2011), decrease aluminium toxicity and improve fertilizer use efficiency (Chan et al., 2007; Van Zwieten et al., 2010a), increase earthworm populations by improving soil conditions (Major et al., 2009; Schmidt and Noack, 2000).

The alkaline nature (pH) of biochar may alter soil pH in a favorable direction for most crops (Chan and Xu, 2009), thereby increasing soil pH and reducing lime requirements.

Though there may be variable percentage of ash in biochar, it is responsible for the modification of the soil‘s pH. The pH of biochar is often above 9 but may vary depending on feedstock and can have a liming value in order of several tens of percent (Van Zwieten et al., 2010c). A pine wood biochar material with a pH of 7.5 was observed to have a lowering effect on the pH of soil with an initial pH of 6.4 (Gaskin et al., 2010). Applying biochar with a liming effect to a soil whose pH is already high can intensify micronutrient deficiencies and reduce crop yields. Several authors (Chan et al., 2008; Laird et al., 2010; Peng et al., 2011; Van Zwieten et al., 2010c) have monitored soil pH in biochar amended soils and in cases where soils pH was found to be lower, a rise in pH has provided several benefits such as improving soil quality (Brady and Weil, 2008). Increases in charge density per unit surface of organic matter which may be linked with the degree of oxidation and or increases in surface charge area for cation adsorption are the likely cause of increases in CEC. There is less CEC and pH effect associated with biochar with low ash content (Van Zwieten et al. 2010a). Cation exchange capacity is the maximum quantity of total cation of any class the soil is capable of holding at a given pH value, available for exchange with the soil solution. In simple words it is the ability of soil to hold onto plant nutrients. pH is important in determining CEC. Since increases in pH increases CEC (soil becomes less acidic and number of colloids increases. Thus the ability of biochar to increase pH is important. The highly porous and large surface area of biochar has an impact on the soil‘s cation exchange capacity (CEC) over time which can be important. Greater soil CEC with biochar additions has been observed in experiments. Chen, et al. (2011) for example found a 24.5% increment in soils CEC treatments with biochar amendment in a high-yielding cropland in the North China Plain.

(c) Influence of biochar on soil water retention

Biochar, a low density and high porous material much like sphagnum moss can be difficult to wet when dry, but can hold large amounts of water. When applied to sandy soil, biochar can improve soil water holding capacity (Briggs et al., 2005; Tryon, 1948) although different biochar materials differ in their ability to positively impact soil water retention.

Novak et al. (2009b) found that biochar made from switch grass improved the water holding capacity of a light textured Norfolk soil more than biochar made from pecan shells, peanut hulls and poultry litter. Biochar applied to clay soils has been found to have no significant effect on water holding capacity (Major, 2009), or to reduce it (Tryon, 1948). Soil aggregation is improved through the interaction of biochar with other soil constituents in some cases. For example, the macroporosity of Terra preta soil was found to be 5-11% greater than that of adjacent soils of similar mineralogy. The long term effect of soil segregation influences soil aeration, water flow and the entire profile of the soil. However there may be some exemptions. Various authors reported on surface water infiltration in biochar-amended soil to be unchanged or improved (Asai et al., 2009; Major, 2009; Husk and Major, 2010). The ability of biochar to retain moisture (through irrigation or rain-fed) will be of much interest to most farmers in regions where water availability for farming is low to prevent moisture stress. Laird et al. 2010 reported that biochar amended soils retained more water at gravity drained equilibrium (up to 15% for 20 g•kg^{-1} treatment), had greater water retention at -1 and -5 bars soil water matric potential, (13% and 10% greater, respectively for 20 g kg^{-1}), and no effect was detected regarding saturated hydraulic conductivity. Treatments consisted of 0, 5, 10, and 20 g-biochar kg^{-1}, with and without manure in a laboratory incubated studies. Again soil water permeability, water holding capacity and saturated hydraulic conductivity were found to have been improved in biochar-amended soils in a field study conducted by Asia et al. (2009).

Significant increases in field capacity of biochar-amended soil were detected at the higher treatment levels of 50 t ha^{-1} and 100 t ha^{-1} of biochar (Chan et al., 2008). Irrigation requirements of soil can be reduced when water retention of soils are enhanced (Liang et al., 2006). This eventually increases the potential for crops to retain more plant available water and thereby increasing crop yields and reducing water stress during critical periods of water restriction.

Taking into consideration the type of soil to which biochar is amended should again be a factor to consider. Sandy soils with low water holding capacity due to macropores and mesopores with little or no organic material will greatly differ from clayey soils that are characterized with micropores (Hillel, 1980). For example, improved water holding capacity with biochar additions is most commonly observed in coarse - textured or sandy soils (Glaser et al., 2002). Amending biochar to soils modifies the pore-system and thereby helps to increase the water content, by adsorbing more water molecules, as the biochar is highly porous and exhibits a variety of binding sites. This means biochar can improve water holding capacity of soils where the pore-system consist of mainly micro-pores (clay or silt) by increasing the hydraulic conductivity and again cause water logging effects in soils where the pore system consist of macro and mesopore (Hillel, 1980). How loose or compact soils maybe (soil strength) can be monitored by bulk density since it influences soil

structure.

Several studies including studies by Gaskin et al. (2008) found that water retention doubled in a loamy sand soil. In a laboratory study by Novak et al. (2009), amending loamy sand with different types of biochar either had no significant effect or increased the water holding capacity of the soil. Chan et al. (2007) obtained similar results working with a hard setting Australian soil, with pot trials. The effect of biochar on soil water retention can be direct or indirect and can be short or long lived (Verheijen et al., 2010).The direct effect relates to biochar‘s large surface area whiles the indirect effect relates to improved aggregation or structure.

(d) Influence of biochar on nutrient availability and retention

Biochar can act as an absorber reducing N leaching and increasing N use efficiency (Steiner et al., 2008) which play a major role to sustain future population growth. There are two general ways through which biochar can influence nutrient availability; 1. Nutrient addition and 2. nutrient retention. Bases such as Ca, Mg, and also P and micronutrients including zinc (Zn) and manganese (Mn) may be available in the ash content of biochar. With the exception of nitrogen, the mineral elements contained in biomass are mostly found in biochar ash. During the pyrolysis process, significant proportions of biomass N are lost by volatilization (Chan and Xu, 2009) and N remaining in the biochar tends to be poorly available to plants (Gaskin et al., 2010), since a fraction of it is found inside aromatic C structures (Chan and Xu, 2009). However the N in biochar derived from one feedstock may differ from another, for example animal manure being an exception (Chan et al., 2008; Tagoe et al., 2008).

It has been reported that biochar application can increase nutrients (total C, organic C, total N, available P, and exchangeable cations Ca, Mg, Na, and K, decrease nutrients such as Al (Chan et al., 2007; Chan et al., 2008; Major et al., 2010b; Van Zwieten et al., 2010a) and increase the uptake of nutrients (Major et al., 2010b). Major et al. (2010b) reported the uptake of nutrients by plants in a biochar amended soil was as a result of greater portions of Ca and Mg in the soil. This was similarly reported by Chan et al. (2007) when biochar produced from poultry litter was used but results differed when green waste based biochar was used. Chan et al. (2008) argues the difference between the two types of biochar used is because of the different rates of lower N in green waste biochar and higher N in poultry litter biochar. Another elucidation given is that biochar amendment can result in microbial growth which causes N mineralization in soil with biochar N not affected by microbes (Chan et al., 2008). An increase in nutrient input may not necessarily lead to increased nutrient uptake but a decrease in leaching and increase nutrient retention in soil mostly for Ca and Mg (Major et al., 2010b).

The nutrient retention capability of biochar is mainly ascribed to its large surface area that provides adsorption sites for inorganic nutrients and to its great porosity composed of both micro- and macropores (Verheijen et al., 2010). The apparent ability of biochar to increase water holding capacity of soils may also improve nutrient retention time in the topsoil. Organic matter or minerals attachment to biochar with sorbed nutrients (aggregation) may further increase the nutrient retention. Biochar particles may however be transported downwards in the soil with water movement or horizontally by surface water runoff, and thereby potentially facilitate the transport of nutrients out of the agricultural system (Major et al., 2010). Biochar additions to the soil can improve fertilizer use efficiency through retained nutrients in the soil. Gathorne - Hardy, et al. (2009) found fertilizer efficiency effect of biochar on spring barley yields in the United Kingdom. Biochar applied at 50 t ha^{-1} combined with 100 Nkg ha^{-1} increased yields by 30% compared to control plots. They hypothesized that the high availability of potassium (K+) in the biochar was able to balance the electrical charge of the nitrate rich soil solution.

Chan et al. (2007) also observed improved N use efficiency in radish growing on an Alfisol amended with 50 and 100 t ha^{-1} of green waste biochar. They attributed the improved efficiency to the beneficial effects of these high rates of biochar on soil physical properties and thus root growth, since this was a hard-setting soil.

Chan and Xu (2009) attributes the increase in fertilizer use efficiency to decreased bulk density, increased water holding capacity and the ability of biochar to retain fertilizer nutrients and reduce leaching losses (Lehmann et al., 2003). Fertilizer additions are not always capable of ameliorating the negative growth responses of fresh biochar additions (Asai et al., 2009). Both the sorptive capacity of biochar and the high C: N ratios are proposed causes for such responses.

2.1.5.3 Influence of biochar on Crop Yield

Generally majority of published studies on the effect of biochar on crop yield are mostly small scale and on short term basis in pots where environmental fluctuations are removed. These may be attributed to lack of methodological consistency in nutrient management and pH control, biochar type and origin. Studies in a wide range of climates, soils and crops have been conducted (Sohi et al., 2009). The literature on the agronomic value of biochar show that very little biochar is utilized in agriculture with few reports available showing a general increase in crop yield and soil quality (Glaser et al., 2002; Chan et al., 2008; Iswaran et al., 1980). Literature has shown a wide range of biochar application rates (0.5 – 135 t/ha), as well as a wide range of plant responses (-29 to 324% increase in dry matter) (Glaser et al., 2002). In all these reports the properties of biochar are not known, contributing very little to results obtained, since the quality of biochar as a soil conditioner depends partly on the characteristics of the biochar.

Thus drawing quantitative conclusions may not, certainly not project or compare the impact of a particular one-time addition of biochar on long-term crop yield. However, evidence suggests that at least for some crop and soil combinations, moderate additions of biochar are usually beneficial, and in very few cases negative (Sohi et al., 2009). A number of early studies conducted during the 1980s and 1990s were reviewed by Glaser (2001). These tended to show marked impacts of low charcoal additions (0.5 t /ha) on various plant species. Higher rates seemed to inhibit plant growth. In later experiments, combination of higher biochar application rates alongside NPK fertilizer increased crop yield on tropical Amazonian soils (Steiner et al., 2007) and semi-arid soils in Australia (Ogawa, 2006). Steiner et al. (2007) reported a doubling up of maize grain yield on plots using combination treatments of NPK fertilizer with charcoal compared to use of NPK fertilizer alone. Though yield gradually reduced during the four cropping cycles on all of the plots, the rate of decline in yield was significantly lower on charcoal amended plots than on those which received only mineral fertilizer. Also, the quantity of nutrients P, K, Ca, and Mg remained higher in charcoal amended plots despite larger amounts of these nutrients having been removed from the soil in the form of harvested plant matter.

This decline in yields distinguishes these charcoal amended plots from true terra preta which is reported to maintain its fertility over many cropping cycles (Glaser, 2001). In a degraded Kenyan Oxisol, Kimetu et al. (2008) found a doubling of cumulative maize yield after three repeated biochar applications of 7 t ha^{-1} over 2 years. Inorganic fertilizers were applied equally in both the biochar-amended and the nonamended control. During the first 3 years, there was an increase in biochar amended plots. A large decrease in overall yields was observed in the fourth year, accompanied by an even greater beneficial effect of biochar (Major et al., 2010a). This shows that biochar application to soil can provide increasing benefits over time.

Oguntunde et al. (2004) investigated the effect of charcoal residue on maize yield in Ghana. It was reported that grain and biomass yield of maize increased by 91% and 44%, respectively on charcoal site soils compared to adjacent field soils (Moses et al., 2011). In another experiment conducted under upland conditions in Laos, biochar without N fertilizer led to the reduction of plant uptake of soil nitrogen, and reported decrease in grain yield despite improved soil physical properties, P availability and nutrient uptake efficiency (Asia et al., 2009).

Table. 2.2: Summary of experiments assessing the impact of biochar addition on crop yield (Woolf, 2008).

Authors	Study outline	Results summary
Lehmann (2003)	Soil fertility and nutrient retention. Cowpea was planted in pots and rice crops in lysimeters at the Embrapa Amazonia Ocidental, Manaus, Brazil	Bio-char additions significantly increased biomass production by 38 to 45% (no yield reported)
Yamato (2006)	Maize, cowpea and peanut trial in area of low soil fertility	Acacia bark charcoal plus fertilizer increased maize and peanut yields (but not cowpea)
Oguntunde (2004)	Comparison of maize yields between disused charcoal production sites and adjacent fields. Kotokosu watershed, Ghana	Grain yield 91% higher and biomass yield 44% higher on charcoal site than control
Chidumayo, (1994)	Bauhinia trees on alfisol/ultisol	Charcoal increased biomass by 13% and height by 24%

Glaser (2002b)	Cowpea on xanthic ferralsol	67 Mgha-1 char increased biomass 150% 135 Mgha-1 char increased biomass 200%
Rondon (2007)	Enhanced biological N_2 fixation (BNF) by common beans through biochar additions. Colombia	Bean yield increased by 46% and biomass production by 39% over the control at 90 and 60 g kg (-1) biochar, respectively.

From the above reports, it can clearly be said that several factors contribute to achieving higher crop yield. They include the type and quantity of biochar applied, soil type and characteristics, climatic conditions, quantity and type of additional nutrient used, type of crop and its growth requirements. Having a general understanding of all these factors can contribute substantively to higher crop productions.

2.2 Maize

Maize or corn (*Zea mays L.*) belongs to the family of grasses (*Poaceae*) and originates from Andean region of Central America. It is cultivated globally being one of the most important cereal crops worldwide (IITA, 1991) both for human and animal consumption (grain and forage). In Ghana, it is produced under different environmental conditions. The production of maize requires proper production techniques such as choosing an appropraite cultivar and soil, proper cultural practices to ensure good economic outputs. For a developing country such as Ghana, maize is consumed directly and serves as staple diet for millions of people.

2.2.1 Climatic and Soil Requirements

In Ghana, maize is usually grown by small-scale farmers, mostly for subsistence as part of agricultural systems that feature several crops and sometimes livestock production. While the very few industrialized systems incorporate extensive inputs, highly mechanized crop production systems and hybrid maize, this systems rather lacks inputs. It is dependent on natural resource base inputs with very little fertilizer use, high reliance on rainfall, and very little or no labour. Thus with current changes in climatic factors such as rainfall patterns, increase population resulting in an intensification of land use, and depletion of soil organic matter and nutrients due to continuous cropping, this system may no longer be an efficient means of production in the future. This is not to deem the industrialized system to be on a much safer path. A clear understanding of climatic and productive factors will enable sustainable use of soil, capital and labour.

2.2.2 Moisture Requirements

Maize requires rainfall of about 600 – 1200mm per annum and this must be well distributed throughout the year (Awuku et al., 1991). This is critical in times of drought since a regular supply of water can prevent wilting in plants. According to Awuku et al. (1991), maize needs water particularly at the time of tasselling and silking. These two stages are very critical since grain formation is initiated during this short period and can greatly influence yield of maize. A number of experiments have shown that water deficiency caused reduced yield of 20% (usually between 1-2 days of wilting) and 50% (usually between 6-8 days of wilting) during tasseling. Adjetey (1994) reported that tasseling is the most sensitive stage to moisture so far as grain yield is concerned. Again, Rouanet (1987) has shown that maize is particularly sensitive to a shortage of water 30 – 40 days either side of flowering.

2.2.3 Soil Requirements

Though maize may thrive well in most soils, Twenebaoh (2000) stated that maize usually requires well-drained, deep loams or silty loams with high to moderate organic matter and nutrient content and pH 5.5 – 8.0 for best production. This was not different from the statement by Adjetey, (1994) which says maize grows on a wide variety of soils but it prefers deep, fertile, well – drained loam and silty loam soil with the soil pH not less than 4.5. Raemaekers (2001) stated that the ideal soil for maize is a deep, medium – textured, well – drained, fertile soil with a high water – holding capacity. Maize is grown in ridges in tropical Africa in the traditional farming system, but it grows better on the flat land (Raemaekers, 2001).

In Ghana, soils of the major maize growing areas are low in organic carbon (<1.5%), total nitrogen (<0.2 %), exchangeable potassium (<100 mg/kg) and available phosphorus (< 10 ppm) (Adu, 1995, Benneh et al., 1990). A large proportion of the soils are also shallow with iron and manganese concretions (Adu, 1969). In spite of these limitations, soil fertility management is low. Fertilizer nutrient application in Ghana is approximately 8 kg ha-1 (FAO, 2005) while depletion rates range from about 40 to 60 kg of nitrogen, phosphorus, and potassium (NPK) ha^{-1} yr^{-1} (FAO, 2005).

2.2.4 Nutrient Requirements

Just as a major requirement in any other crop production, maize requires large amounts of nutrients to grow. Organic and inorganic fertilizer have been used in Ghana on continuously and previously used land (Awuku et al., 1991). They further stated nitrogen as one of the most important nutrient needed in large quantities for maize development. It is mostly applied in split application before and after tasselling because it easily leaches through the soil. Nitrogen as an integral component of many compounds essential for plant growth processes including chlorophyll and many enzymatic activities (Roth and Fox, 1990) also play a major role in plant physiological processes (Raven et al., 1999). The optimum utilization of other nutrients such as potassium, phosphorous and other elements are facilitated by nitrogen. Therefore, nitrogen deficiency can result in reduced maize yield. There have been several figures by different authors on maize nitrogen requirements depending on environmental factors like irrigation, varieties, soil type, cropping history of the field and expected yield. For example Singh et al., (2000) reported that N at 180 kg/ha and 200 kg/ha are optimum for maize yield. In another study conducted, an application of 50, 100 and 150 kg/ha N with 60 kg/ha P increased crop yield (Arain et al., 1989). A maximum yield of about 3 t/ha was recorded when 92 kg/ha N was applied alongside 40kg/ha P (Chaudhry et al., 1991). Sabir et al., 2000; Yamoah et al. 2002; Aflakpui et al., 2005; Conley et al. 2005 all have reported increase in maize grain yield with an increased in the rates of nitrogen application.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The study was conducted at the Faculty of Renewable Natural Resources farm at the Kwame Nkrumah University of Science and Technology, Kumasi (KNUST). The area falls within the moist semi-deciduous forest zone of Ghana. The area is characterized by a bimodal rainfall pattern, with the major wet season between May and July. The annual rainfall ranges between 1200 to 1500 mm with a mean annual temperature of 26.6^{o}C and a mean annual humidity of 67.6%. The soils are classified as ferric acrisol with a sandy-loam textural class (FAO, 1988). The experiment was conducted in two cropping seasons: minor cropping season (September to December 2012) and major cropping season (March to June 2013).

3.2 Experimental Design and Field Layout

The two factors studied were biochar produced from *Tectona grandis* shavings (F1) and inorganic N fertilizer (F2). Factor 1 (biochar) was applied at 5 levels : 0, 5, 10, 15 and 20 t ha^{-1} whiles Factor 2 (inorganic N fertilizer) was applied at 3 different rates of nitrogen (0 kg N, 45 kg N and 90 kg N ha^{-1}). Potassium and phosphorous were applied at basal rate of 60 kg P ha^{-1} and 60 kg K ha^{-1} to all plots. Using a 3 x 5 factorial experiment in a randomized complete block design (RCBD), 15 treatment combinations were replicated 3 times resulting in 45 experimental units (Table 3.1).

Each plot was 6.4 m^{2} (3.2 m x 2 m) in size.

Table 3.1: Experimental treatments units used for the two seasons field study

TREATMENTS	†B0	B1	B2	B3	B4
F0	B0F0	B1F0	B2F0	B3F0	B4F0
F1	B0F1	B1F1	B2F1	B3F1	B4F1
F2	B0F2	B1F2	B2F2	B3F2	B4F2

†B0, B1, B2, B3 and B4 represent biochar applied at 0, 5, 10, 15 and 20 t ha^{-1}. F0, F1 and F2 represent inorganic fertilizer N applied at 0, 45 and 90 kg ha-1 respectively.

3.3 Biochar Preparation

Biochar was produced from *Tectona grandis* and was pounded, homogenized and sieved to 3 mm particle size to increase interaction with soil mineral particles. Biochar was produced by local charcoal producers by earth mound method (FAO, 1983). To analyze for chemical properties, the biochar was broken and ground to pass through a 0.5 mm sieve. Samples of the biochar were characterized for pH, total N, P and C in three replicates. Biochar was applied and incorporated within 10 cm of the soil with a rake as described by Novak et al. (2009). Biochar was applied prior to planting in the first (minor) cropping season.

3.4 Land Preparation

The 644 m^2 plot had been used for maize production the previous year. The existing biomass was slashed and removed. The plot was demarcated and labeled according to treatments applied. This process was done for the two cropping seasons.

3.5 Planting

Maize seeds were obtained from the CSIR-Savanna Agricultural Research Institute in

Tamale, Northern region. The variety of maize used was an early maturing variety, *Dorke*. An initial viability test was conducted on seeds to establish the quality of seeds as well as its efficacy for germination. This was done using simple germination test and the germination percentage was 98%. Three seeds were sown per hill and thinned to two seedlings per hill two weeks after emergence. The planting spacing used was 80 cm between rows and 40 cm between plants. The seeds were sown at 3-5cm depth.

3.6 Cultural Practices

Weeding was done manually with hoes at 3, 7 and 10 weeks after planting (WAP). Earthing up was carried out alongside weeding in the 10th week to provide support for plants against root lodging. Fertilizer application was done in two split applications using the placement (localized) method. Fertilizer was applied close to the plant in order to supply nutrients adequately to the roots. First application was at 2 WAP and the second at 6 WAP. Basal application of all phosphorus and potassium and one-half the rate of nitrogen was applied 2 WAP. The remaining nitrogen application was done 6 WAP. Fertilizer application was done for each of the two cropping seasons.

3.7 Plant Sampling and Analysis

Above ground biomass was determined at harvesting using 15 plants per treatment excluding plants in the border rows. Plants were carefully uprooted from soil and separated from roots. The shoots were enveloped and oven-dried in the laboratory at 65^{o}C till constant weight for analysis. Grain yields were also measured at harvest stage using the fresh weight of grains collected from 15 plants per plot. Relative increases were calculated compared to the control using a relation modified from Gachengo et al. (1999):

$$\text{Yield increase } \% = \frac{\text{Grain yield from amended plots}}{\text{Grain yield from control plots}} X\ 100\% \quad (3.1)$$

These procedures were repeated for the second cropping season.

Nitrogen uptake (N uptake) in the aboveground biomass of the maize was determined at physiological maturity for each cropping season. Plant samples were collected per plot and oven dried at 65^{o}C to constant weight. Dried material was ground, passed through a 0.5 mm sieve and analyzed for N concentrations using the Kjeldahl method. Nitrogen uptake was determined by multiplying the dry-matter yields by the N concentration. Results on N uptake was used to calculate N use efficiency (NUE) using the relation by Fageria et al. (2010):

$$\text{NUE } \% = \frac{\text{N uptake on amended plots} - \text{N uptake on control plots}}{\text{Total N applied}} \text{ x } 100\% \quad (3.2)$$

3.8 Soil Sampling and Analysis

For each of the cropping seasons, before and after planting, soil samples were collected randomly to the depth of 20 cm at the experimental site for site characterization. Five samples were randomly collected per plot, bulked, homogenized, sub-sampled, air-dried and passed through a 2 mm sieve for the analysis. Each sample was analyzed for soil pH, total N, mineral N, organic carbon, effective cation exchange capacity (CEC), available P and exchangeable K.

3.9 Laboratory Analytical Procedures for Soil Chemical Parameters

(a) Soil pH

Soil pH was determined using the glass electrode pH meter. Twenty five milliliter (25 ml) of distilled water was added to 10 g of soil and stirred for 20 minutes. The mixture was allowed to stand for 30 minutes before inserting electrode into soil suspension to measure the soil pH.

(b) Organic Carbon and Organic Matter (OM)

Organic matter was determined using the dry combustion method. Ten grams (10 g) of the sample was weighed into a crucible and oven dried at 105^{o}C for 4 hours. The crucible with the sample was then removed from the oven and allowed to cool before weighing (w1). The sample was then ashed in a muffle furnace at a temperature of 400^{o}C for 4 hours. The sample was then removed from the furnace and allowed to cool before weighing (w2).The percentage organic matter and organic carbon was determined using the following formula:

% OM = (w1-w2)/w1 x 100 (3.3)

% Organic Carbon = % OM x 0.58 (3.4)

(c) Bulk density

The soil bulk density was measured as described by Anderson and Ingram (1993). Four soil samples were randomly collected from each replicate by inserting a core metal tube of known weight (W1) and volume (V) deep into the soil. The soils at both ends of the tube were trimmed and flushed with a knife. The soil was then dried in the oven for 2 days at 105^{0}C. After which the weight (W2) was taken. The bulk density was determined using the equation below:

Bulk density = (Pb) g/cm3 (3.5)

(d) Total Nitrogen

Kjeldahl digestion method was used to determine Total N. Ten grams (10 g) of distilled water was added to 10 g of soil in a Kjeldahl flask and allowed to stand for 10 minutes to moisten it. One spatula of Kjeldahl catalyst (1part selenium+10 parts $CuSO_4$+100 parts Na_2SO_4) and 20 ml conc. H_2S0_4 was then added to the mixture. The solution was then digested until it was clear and colorless. The flask was allowed to cool and the solution transferred into a 100 ml volumetric flask and make up to the mark with distilled water.

Twenty millilitres (20 ml) of 40% NaOH was then added and distil over 10 ml of 4% Boric acid and three drops of indicator for 4 minutes. This changed the solution to light blue colour. The distillate was then titrated with 0.1 N HCl until the light blue colour changed to grey and then back to pink. Weight of soil sample used, considering the dilution and the aliquot taken for distillation was expressed as:

$$\frac{10g \times 10\ ml}{100ml} = l\ g$$

The percentage N content of the soil was calculated using the relation:

$$\%\ N = \frac{14 \times (A - B) \times N \times 100}{1000 \times 1} \quad (3.6)$$

Where: A = volume of standard HCl used in the sample titration

B = volume of standard HCl used in the blank titration

N = Normality of standard HCl

(e) Available Phosphorus

Twenty millilitres (20 ml) of Bray P1 extracting solution was added to 2 g of soil in a 50 ml shaking bottle and placed on a mechanical shaker for 1 minute. The mixture was then filtered and 10 ml of the filtrate pipetted into a 25 ml volumetric flask. One millilitre (1.0 ml) of molybdate was then added followed by 1.0 ml of dilute reducing agent. This changed the solution into a blue colour. Distilled water was then added to the 25 ml mark. It was then shaken vigorously and allowed to stand for 15 minutes before measuring the percent transmission at 600 nm wavelength on a colorimeter. The percentage transmittance (T) values were then recorded. The P content was determined from a standard curve. The following equations from the standard curve, was obtained:

$Y = AX$

Therefore available phosphorous (P) ppm or mg/Kg

$X=Y/A \times 10$ (3.7)

Where $Y= 2- \log T$ of the sample

A =a constant obtained from the graph

(f) Exchangeable Cations

The exchangeable metallic cations which are those cations on colloid surfaces that are replaceable by other cations from the soil solution were measured as described by Moss, (1961). Hundred millilitres of 1.0N NH_4OAc solution was added to 10g of soil in an extraction bottle. The mixture was then placed on a mechanical shaker for an hour. It was then filtered with No.42 Whatman filter paper and the aliquots of the filtrate used to determine Calcium (Ca), Magnesium (Mg), Potassium (K) and Sodium (Na).

i. Calcium and Magnesium

Ten milliliters (10 ml) of 10% KOH solution followed by 1ml of 30% triethanolamine were added to a 10 ml of aliquot sample solution (as prepared above). Three drops of 10% KCN solution and few crystals of Cal-red indicator were added and shaken vigorously for a uniform mixture. The mixture was then titrated with 0.02 N EDTA solution to obtain change from red to blue endpoint to determine Ca.

Magnesium was determined by finding the Ca+Mg value and subtracting the value of Ca from it. The Ca + Mg was determined by adding 5 ml of ammonium chlorideammonium hydroxide buffer solution followed by 1 ml of triethanolamine in a 10 ml aliquot solution (prepared above). Three drops of 10% KCN and a few drops of EBT indicator were added and shaken vigorously for uniform mixture. The mixture was titrated with 0.02 N EDTA solution to obtain a change from red to blue endpoint.

ii. Potassium and Sodium

Ten millilitres of the aliquot solution was used to determine for K and Na by reading from a flame photometer. The emission values were read on the flame analyzer. A standard curve was obtained by plotting the emission values against their respective concentrations. The amount of K and Na were determined using the formula below

$$Y = BX \quad (3.8)$$

Therefore K and Na Cmol/kg =

$X = (Y/B) \div 39.1$

X= K and Na Cmol/kg

Y= flame photometer reading of the sample

B= constant value from the curve

39.1= atomic weight of K and Na

iii. Aluminum (Al) and Hydrogen (H)

Hundred milliliters (100 ml) of 1N KCl solution was added to 5 g of the soil and shaken for 2 hours on a mechanical shaker. The mixture was filtered and 25 ml of the filtrate measured into a 250 conical flask. One hundred and fifty milliliters (150 ml) of distilled water and four drops of phenolphthalein indicator were added to the filtrate. The solution was them titrated with 0.05N NaOH to obtain a pink colour from the original colorless condition. This gave the value of Al. A few drops of 0.05 HCl was then added which changed the colour back to colourless. Ten milliliters (10 ml) of 1N sodium fluoride (NaF) was again added to change the colour back to pink. The solution was again titrated with 0.5 N HCl to a colourless condition to give the value of Al + H_2. The value of Al was subtracted from the Al and H_2 value to give the value of H_2 alone.

(g) Mineral Nitrogen

Indophenol blue method

A sample volume of 25mL was transferred into a 50-mL Erlenmeyer flask, then 1mL phenol solution, 1mL sodium nitroprusside solution and 2.5mL oxidising solution was added with thorough mixing after each addition. The sample was covered with plastic wrap or parafilm and kept in the dark at room temperature (22 to 25^0C) for at least 1 hour. The absorbance was measured at 640 nm. Six standards were used to prepare the calibration graph. The blank was treated like the standards. The result was expressed in NH_4 mg /L.

3.10 Statistical Analysis

All parameters measured were statistically analyzed using Analysis of Variance (ANOVA) test. Treatment means were compared using the least significant difference method at 0.05 probability level. All statistical analyses were conducted using GENSTAT (version 11) software.

CHAPTER FOUR

RESULTS

4.1 Site Characterization

Initial soil analyses conducted showed the textural class of the soil was sandy loam with pH of 5.83 and total nitrogen of 0.05% (Table 4.1). The chemical composition of biochar used indicated a C/N ratio of 122. With the exception of organic carbon, the content of other parameters measured were relatively low (Table 4.2)

Table 4.1: Initial soil physicochemical properties of the top-soil (0-20 cm) of the experimental site at the Faculty of Renewable Natural Resources Research Farm.

Parameter	Value
pH (H_2O) 1:1	5.83 (0.3)
Organic carbon (g/kg)	1.2 (0.1)
Total Nitrogen (g/kg)	0.5 (0.0)
Organic matter (g/kg)	2.07 (0.3)
Available P (mg/kg)	7.81 (0.2)
Exchangeable K (mg/kg)	82.87 (3.5)
Exchangeable cations (cmol/kg) Ca	
	2.67 (0.1)
Mg	1.60 (0.2)
K	0.12 (0.0)
Na	0.08 (0.0)
Exchangeable Acidity (Al+H) (cmol/kg)	0.45 (0.0)
Effective Cation Exchange Capacity (cmol/kg)	4.92 (0.1)
% Base saturation	90.85 (0.1)
Texture (%) Sand	62 (4.3)
Clay	15 (8.1)
Silt	23 (7.9)
Textural class	Sandy-loam

Values are the means of three replicates. Values in parentheses are standard error of means.

Table: 4.2: Chemical composition of biochar applied in the experiment

Nutrient parameter	P	K	Ca	Mg	Organic C	Total N	C : N	CEC
			g/kg					(Cmol/ kg)
Content	0.05 (0.0)	3.6 (0.2)	4.6 (0.1)	0.4 (0.1)	890.7 (3.2)	7.3 (0.1)	122 (0.3)	10.9 (0.2)

Values are the means of three replicates. Values in parentheses are standard error of means.

4.2 Effects of biochar and inorganic N fertilizer on some soil properties

Analysis of variance showed biochar significantly influenced CEC ($p = 0.001$), pH ($p = 0.05$) and mineral N ($p = 0.05$) (Table 4.3). With the exception of pH, fertilizer N and biochar interaction significantly influenced CEC and mineral N (Table 4.3). The effect of biochar applied at 5 and 10 t/ha on CEC was similar but significantly higher than the control (B0), while 15 t/ha (B3) and 20 t/ha (B4) were also similar and were significantly higher than 5 t/ha (B1) and 10 t/ha (B2) (Figure 4.1)

Biochar application increased soil pH relative to the control (Figure 4.2). Raising biochar rate to 15 t/ha brought marginal increase in soil pH. However, biochar level above 15 t/ha resulted in a marginal drop in soil pH. Increasing rate of biochar application resulted in significant increase in mineral N. However, biochar rate higher than 10 t/ha resulted in significant decrease in soil mineral N (Figure 4.3).

With the exception of the control plot (F0B0), addition of biochar resulted in significant increase in CEC at each fertilizer N level. However, raising biochar application above 5 t/ha brought about marginal changes in CEC. (Figure 4.4). Figure 4.5 showed increasing levels of biochar resulted in increases in mineral N levels at each level of fertilizer. However biochar level above 10 t/ha resulted in significant decrease in soil mineral N.

Table 4.3: Analysis of variance summary for the effects of biochar and fertilizer application on soil chemical parameters

		CEC (cmol/kg)	PH (1: 1 H_2O)	Mineral N (mg/kg)
Biochar	4	5.29 **		
Fertilizer N	2	0.02ns	0.02ns	126.37ns

Biochar * Fertilizer N	8	1.42*	0.03ns	265.35*	Source DF
Residual	28	0.62	0.15	55.95	
			0.43*	45.08*	

------------------ Mean Squares ---------------------

* Significant at p≤ 0.05, ** Significant at p≤ 0.01, ns: Not significant

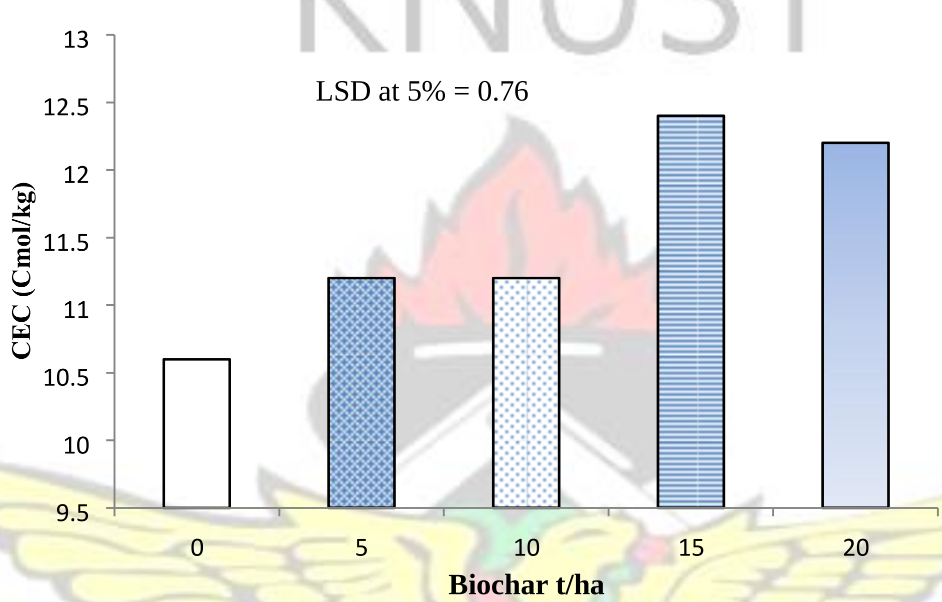


Figure 4.1: Effects of biochar application on cation exchange capacity (CEC). Data points are the means of 3 replicates. LSD = Least Significant Difference

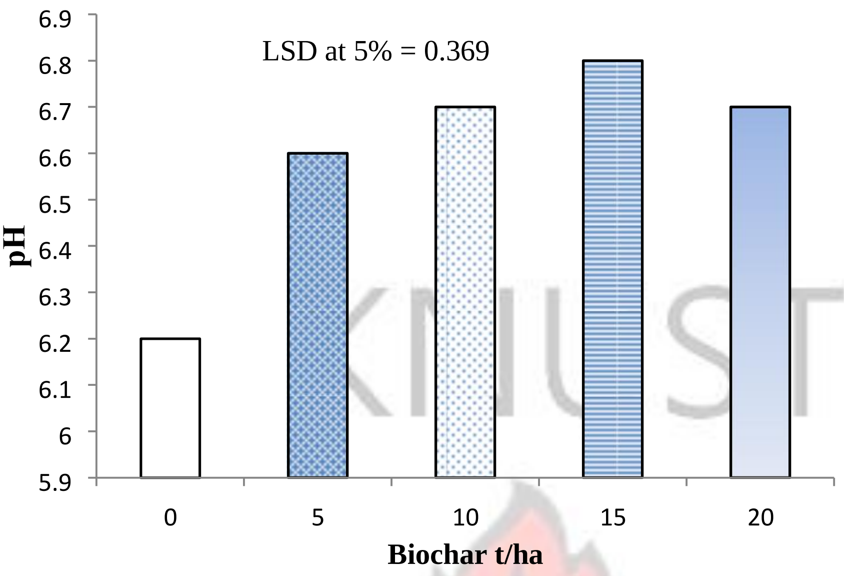


Figure 4.2: Effects of biochar application on soil pH. Data points are the means of 3 replicates. LSD = Least Significant Difference.

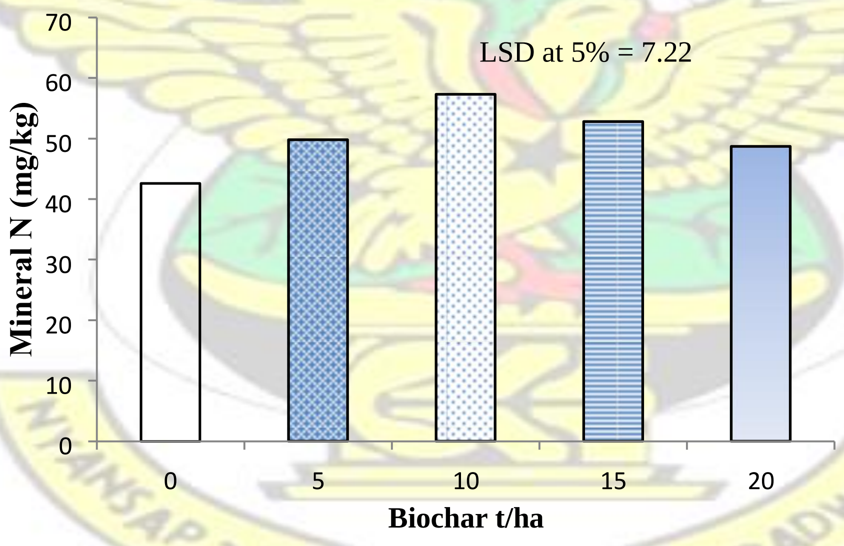
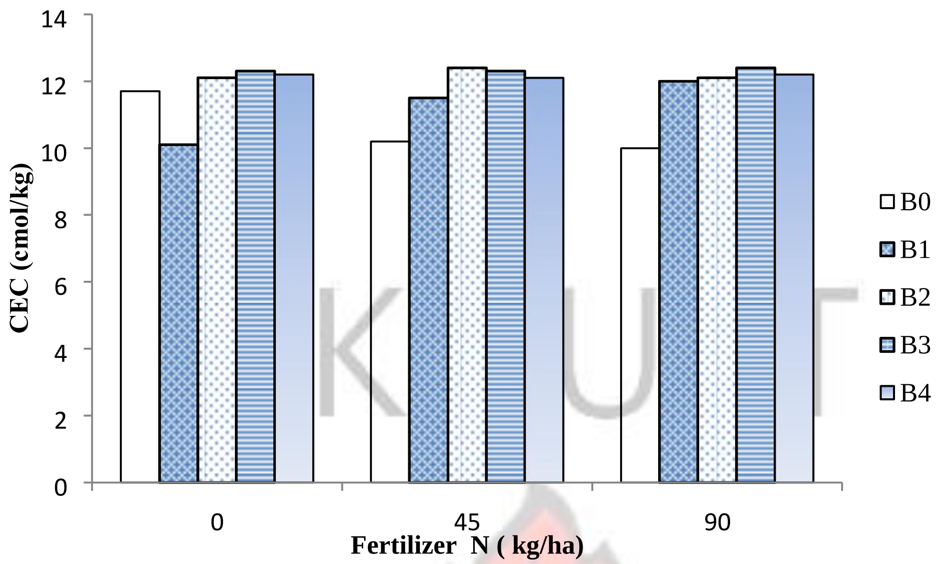


Figure 4.3: Effects of biochar application on soil mineral N. Data points are the means of 3 replicates. LSD = Least Significant Difference.



LSD at 5% = 1.316

Figure 4.4: Effects of biochar and inorganic N fertilizer application on cation exchange capacity (CEC). BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 tha^{-1} respectively. Data points are the means of 3 replicates. LSD = Least Significant Difference.

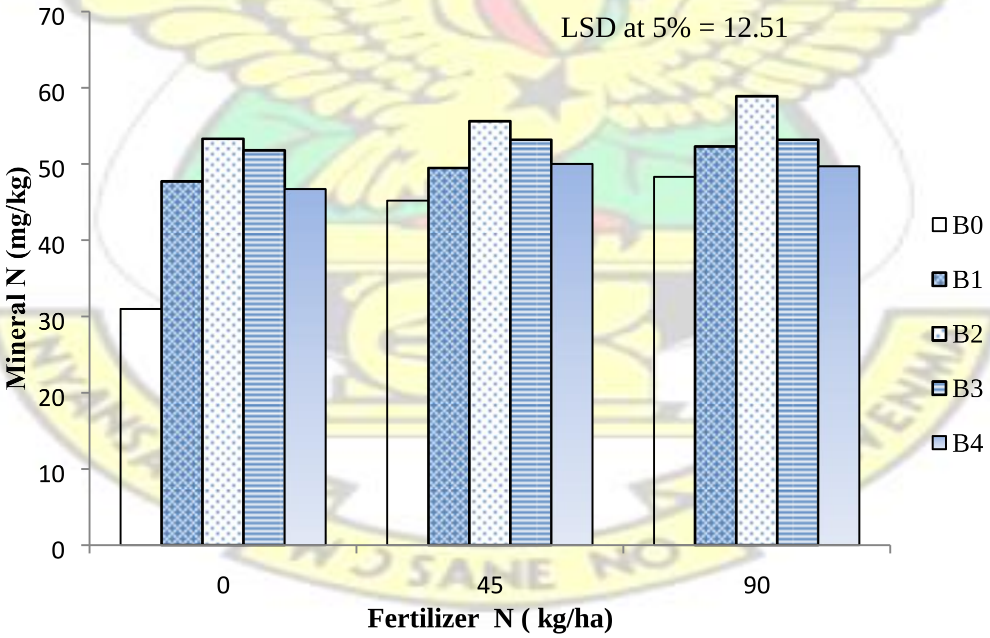


Figure 4.5: Effects of biochar and inorganic N fertilizer application on mineral N. BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 tha^{-}

[1] respectively. Data points are the means of 3 replicates. LSD = Least Significant Difference.

4.3 Effects of Biochar and inorganic N fertilizer on grain yield of maize Analysis of variance showed biochar and fertilizer N interaction significantly influenced grain yield of maize in both minor ($p = 0.001$) and major cropping seasons ($p = 0.014$) (Table 4.4). The sole application of biochar or inorganic fertilizer N also significantly influenced maize grain yield in both minor and major cropping seasons. Maize grain yield increased significantly with increasing biochar application at each fertilizer N rate (Figures 4.6 and 4.7). However, biochar rate higher than 10 t/ha resulted in decrease grain yield at all fertilizer N rates in both cropping seasons. While in the minor season of 2012, raising fertilizer N resulted in increase in maize grain yield at zero biochar, in the major season of 2013, raising N rate above 45 kg/ha did not result in significant yield increase. In both cropping seasons, biochar at 10 t/ha with inorganic fertilizer N resulted in highest grain yield. In both seasons, biochar applied at 10 t/ha (B2) with fertilizer N applied at both 45 and 90 kg/ha resulted in significantly higher grain yield than grain yield obtained at higher biochar rate with the same fertilizer rate. In both seasons, plots that received both biochar at 10 t/ha (B2) plus 90 kg N/ha (F2) recorded the highest grain yield

The application of biochar significantly ($p = 0.001$) increased the grain yield of maize in both minor and major cropping seasons. Relative to the control (BO), the application of biochar at 10 t/ha increased grain yield by 213% and 160% in the minor and major cropping seasons respectively.

Moreover, the application of N fertilizer significantly ($p = 0.05$) increased the grain yield of maize in both minor and major cropping seasons (Figure. 4.8). Among fertilizer treatments, the greatest grain yield was recorded on plots that received 90 kg N ha^{-1}.

Relative to the control, grain yield with 90 kg N ha^{-1} application was 140% and 175% greater than the control during the minor and major cropping seasons, respectively. While the sole application of N fertilizer or biochar generally increased grain yield of maize, the impact of its interaction was greater.

Table 4.4: Analysis of variance summary of grain yield of maize as affected by biochar and inorganic N fertilizer applications under field conditions

		Grain yield (t ha^{-1}) Minor rainy season	Grain yield (t ha^{-1}) Major rainy season
Source	DF	----------- Mean Squares	-----------
Biochar	4	1.03**	1.25**
Fertilizer N	2	0.09*	0.37**
Biochar * Fertilizer N	8	0.13**	0.06*
Residual	28	0.01	0.02

* Significant at p≤ 0.05 ** Significant at p≤ 0.01, ns : Not significant

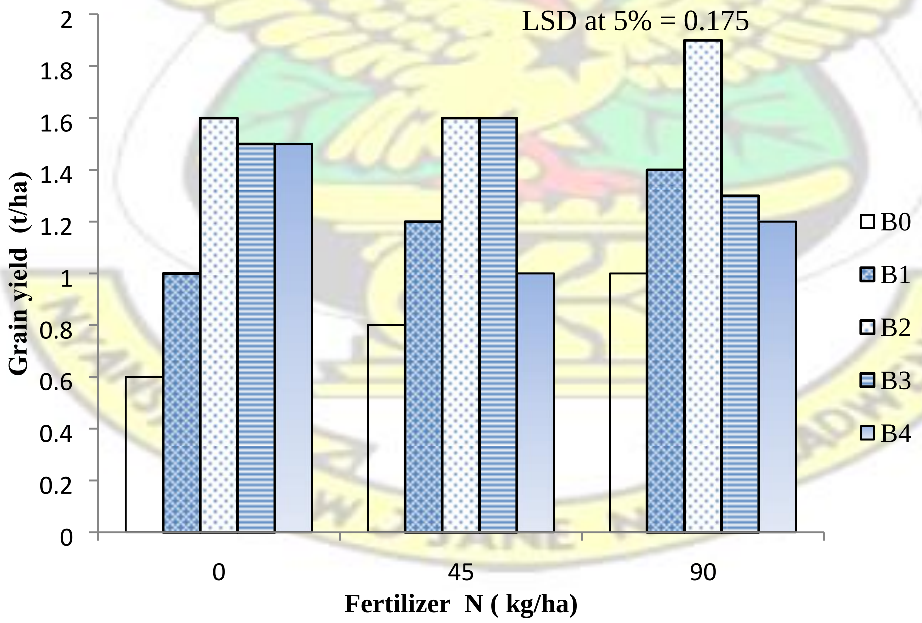


Figure 4.6: Effects of biochar and inorganic N fertilizer application on grain yield of maize in the minor cropping season of 2012. BO, B1, B2, B3 and B4 are biochar

amendments applied at 0, 5, 10, 15 and 20 t ha^{-1} respectively. Data points are the means of 3 replicates. LSD = Least Significant Difference.

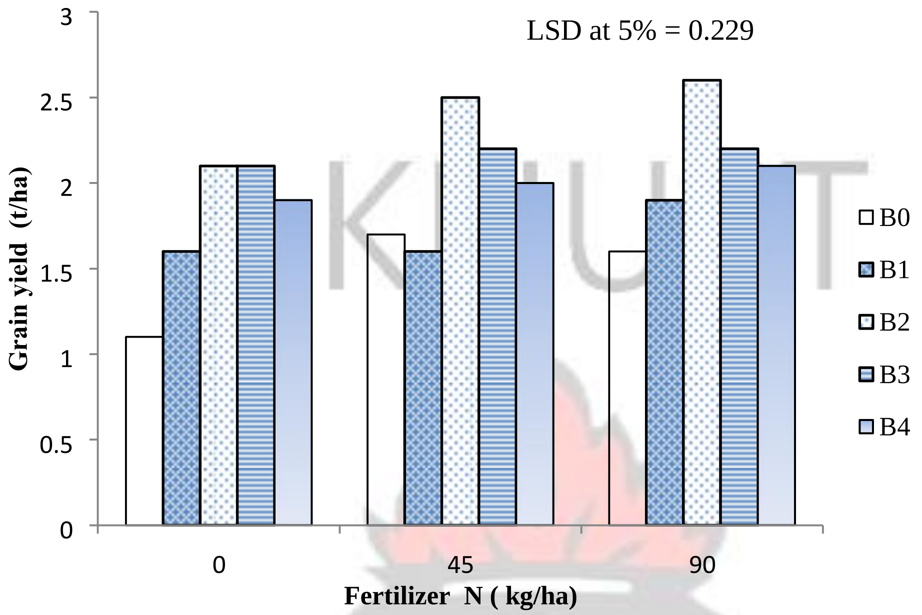


Figure 4.7: Effects of biochar and inorganic N fertilizer application on grain yield of maize in the major cropping season of 2013. BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 t ha^{-1} respectively. Data points are the means of 3 replicates. LSD = Least Significant Difference.

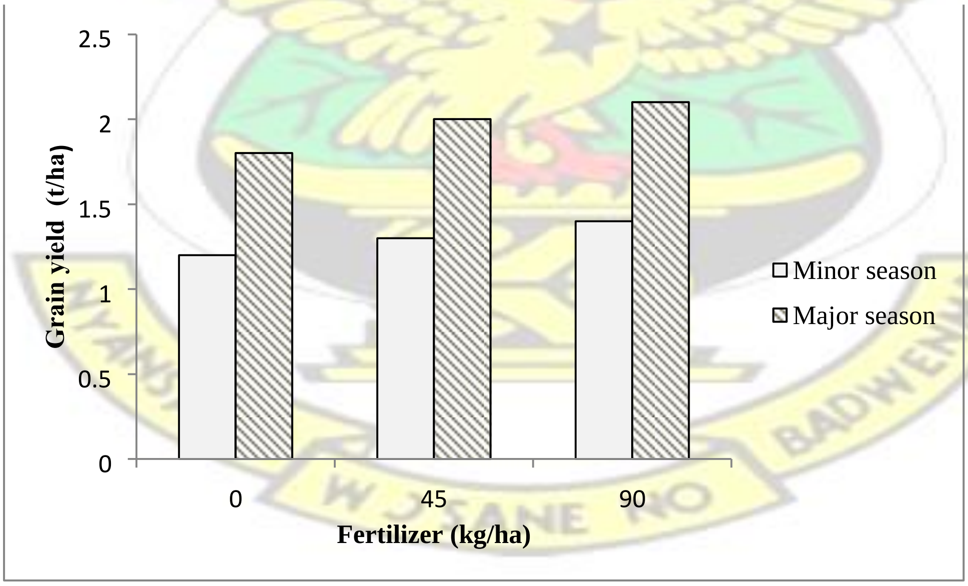


Figure 4.8: Effects of inorganic N fertilizer application on grain yield of maize in the minor and major cropping seasons. Data points are the means of 3 replicates.

4.4 Effects of biochar and inorganic N fertilizer application on maize stover yield

The analysis of variance showed fertilizer N and biochar application significantly (p = 0.001) increased the stover yield of maize in both cropping seasons. Increasing rate of biochar application rate resulted in significant increase in maize stover yield but biochar rates higher than 10 t/ha resulted in decrease of stover yield at all fertilizer rates applied in both two cropping seasons (Figures 4.9 and 4.10).

In the minor cropping season, stover yield ranged from 1.3 t/ha to 4.1 t/ha while in the major cropping season, it ranged from 2.3 t/ha to 5.4 t /ha (Figures 4.9 and 4.10). Relative to the control, stover yield was about 148% higher on sole biochar amended plots with 10 t/ha recording the greatest impact.

In addition, the study showed increased stover yield of maize with sole N fertilizer application. In all the two cropping seasons, N fertilizer applied at 90 kg/ha recorded the greatest stover yield. Although sole fertilizer or biochar application increased stover yield of maize, the effect was significantly higher when both treatments were combined. Total stover yield at 10 t/ha and 90 kgN/ha application was about three times that of the control.

Table 4.5: Analysis of variance summary of stover yield of maize as affected by biochar and inorganic N fertilizer applications under field conditions

		Stover yield (t ha^{-1}) Minor rainy season	Stover yield (t ha^{-1}) Major rainy season
Source	DF	---------- Mean Squares	------------
Biochar	4	5**	4.58**
Fertilizer N 2 Biochar *		0.19*	0.94**
Fertilizer N 8		0.65**	0.36**
Residual	28	0.04	0.02

* Significant at p≤ 0.05, ** Significant at p≤ 0.01, ns: Not significant

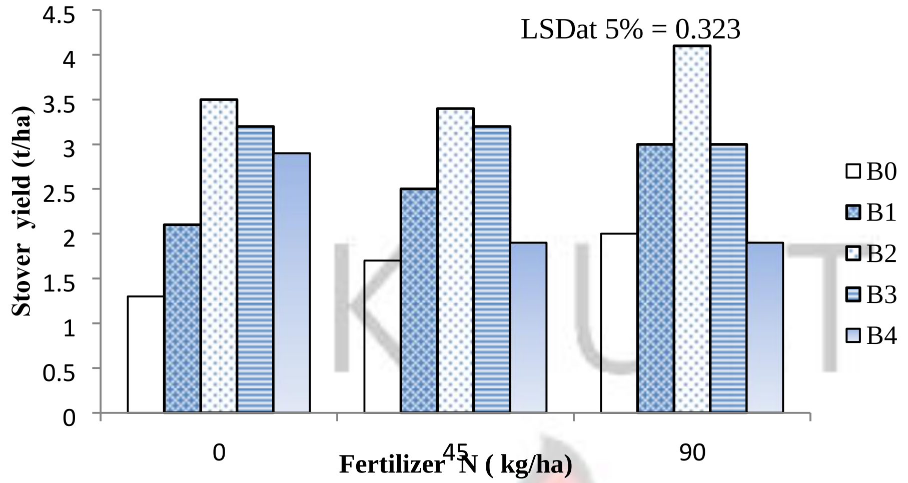


Figure 4.9: Effects of biochar and inorganic N fertilizer application on stover yield of maize in the minor cropping season of 2012. BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 t ha^{-1} respectively. Data points are the means of 3 replicates. LSD = Least Significant Difference.

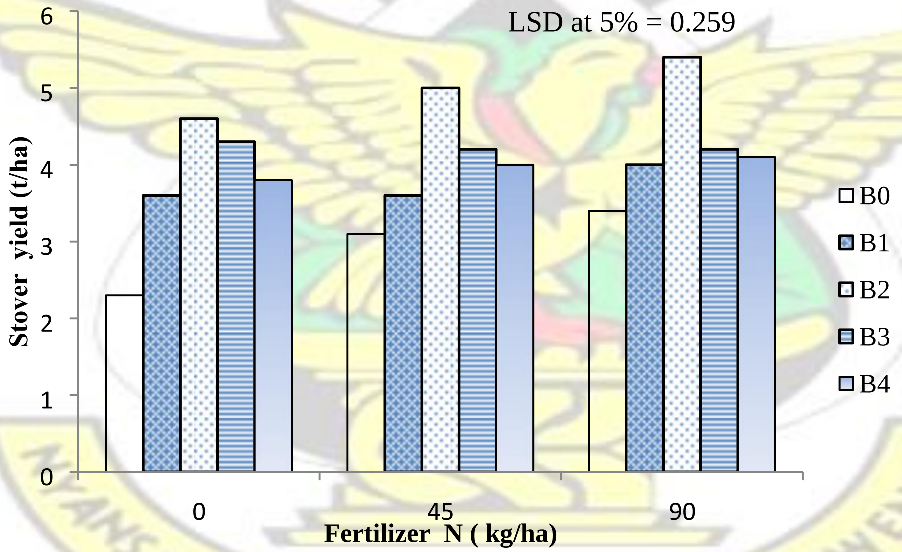


Figure 4.10: Effects of biochar and inorganic N fertilizer application on stover yield of maize in the major cropping season of 2013. BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 t ha^{-1} respectively. Data points are the means of 3 replicates. LSD = Least Significant Difference.

4.5 Effects of biochar and inorganic N fertilizer application on Nitrogen Uptake of Maize

Nitrogen uptake was significantly (p = 0.001) increased in maize plants that received biochar with or without inorganic N fertilizer application. In the minor season, sole biochar application increased N uptake by 222.8% when applied at 10t/ha. Comparably, application of inorganic N fertilizer at 90 kgN/ha (F2) also increased N uptake by 252.7%. Again, the combined effect of biochar and inorganic fertilizer N increased N uptake by 1040% when biochar and fertilizer were applied at 10 t/ha and 90 kgN/ha (B2F2). These results were consistent with what was obtained in the major season. In both minor and major cropping seasons, biochar application increased N uptake in the order: BO < B1 < B4 < B3 < B2 (0, 5, 20, 15 and 10 t/ha respectively) whiles fertilizer N increased N uptake in the order: FO < F1< F2 (0, 45 and 90 kgN/ha).

The interactive effect of biochar and inorganic fertilizer N showed increasing rate of biochar application resulting in significant increase in maize N uptake (Figures 4.11 and 4.12). However, biochar rate higher than 10 t/ha resulted in decreased N uptake at all applied fertilizer rates in both cropping seasons. Furthermore, in both cropping seasons, biochar applied at 10 t/ha and fertilizer N applied at 90 kgN/ha (B2F2) recorded the highest N uptakes and this was about two times that of the control (BOFO).

Table 4.6: Analysis of variance summary on the effects of biochar and inorganic N fertilizer on maize N Uptake

	N uptake (kg ha^{-1}) Minor rainy season	N uptake (kg ha^{-1}) Major rainy season

Biochar		500.7**	747.96**
Fertilizer N		1867.43**	2789.62**
Biochar * Fertilizer N			
Residual	28	30.5	1.623

* Significant at p≤ 0.05, ** Significant at p≤ 0.01, ns: Not significant

Source	DF	---------- Mean squares	------------------------ 4
	2		
	8	46.78**	69.89**

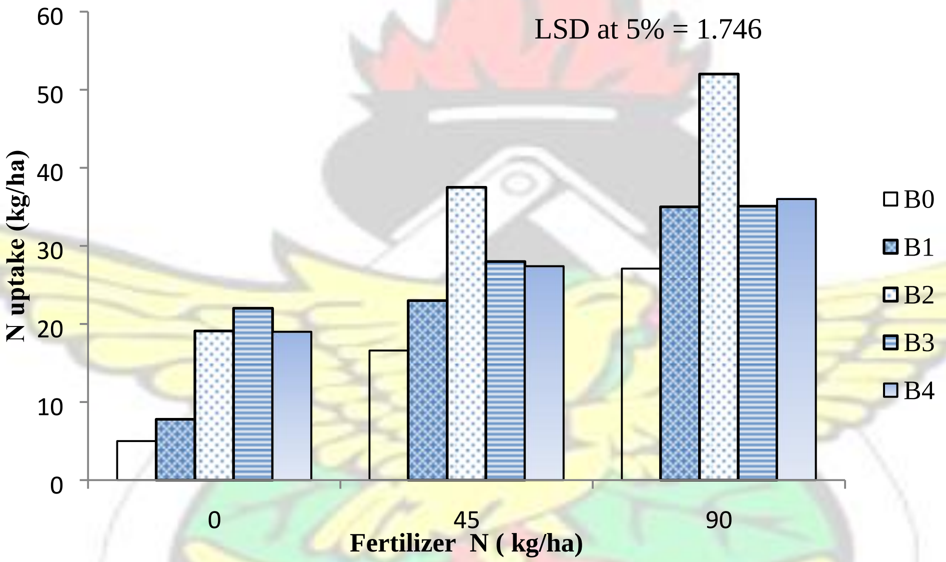


Figure 4.11: Effects of biochar and inorganic N fertilizer application on N uptake of maize in the minor cropping season of 2012. BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 t ha^{-1} respectively. Data points are the means of 3 replicates. LSD = Least Significant Difference.

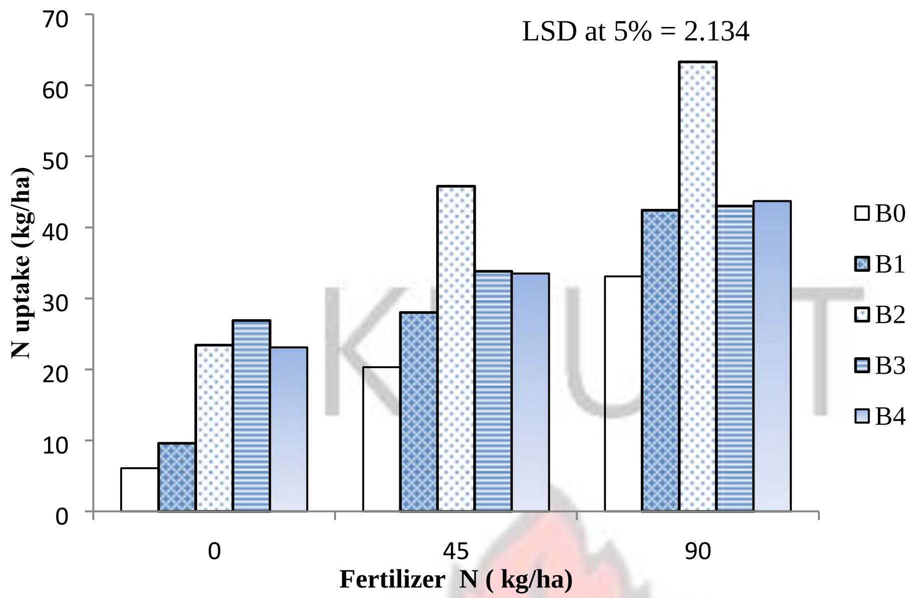


Figure 4.12: Effects of biochar and inorganic N fertilizer application on N uptake of maize in the major cropping season of 2013. BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 t ha^{-1} respectively. Data points are the means of 3 replicates. LSD = Least Significant Difference.

4.6 Effects of biochar and inorganic N fertilizer application on Nitrogen Use Efficiency (NUE) of Maize

Biochar and fertilizer N application significantly (p = 0.001) increased nitrogen use efficiency (Table 4.7) in both minor and major cropping seasons. NUE was highest when biochar was applied with inorganic N fertilizer either at the 45 or 90kgN/ha (Figures 4.13 and 4.14). Among all treatments, NUE was highest when biochar and fertilizer was applied at 10t/ha plus 90 kgN/ha (B2F2) and lowest at 5 t/ha biochar (Figure 4.15). The interactive effect of biochar and inorganic fertilizer N showed biochar rates higher than 10 t/ha resulted in decreased nitrogen use efficiency of maize at all applied fertilizer rates.

Table 4.7: Analysis of variance summary on the effects of biochar and inorganic N fertilizer on maize Nitrogen use efficiency (NUE)

Source	DF	NUE of maize (%) Minor rainy season	NUE of maize (%) Major rainy season
		----------- -- Mean	Squares ----------------
Biochar	4	229.83**	343.32**
Fertilizer N	2	523.52**	782.05**
Biochar * Fertilizer N	8	105.99**	158.33**
Residual	28	30.5	1.26

* Significant at p≤ 0.05, ** Significant at p≤ 0.01, ns Not significant

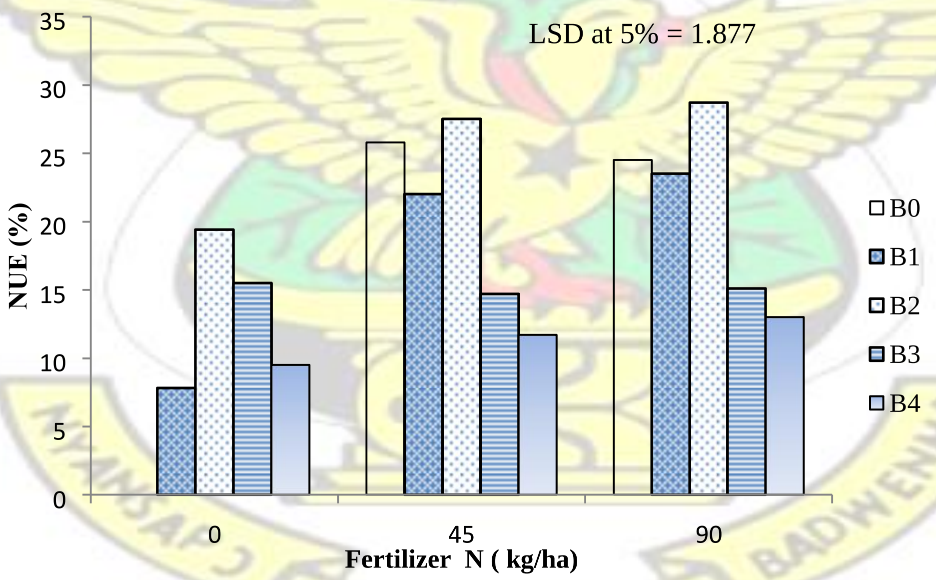


Figure 4.13: Effects of biochar and inorganic N fertilizer application on NUE of maize in the minor cropping season of 2012. BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 t ha^{-1} respectively. Data points are the means of 3 replicates. LSD = Least Significant Difference.

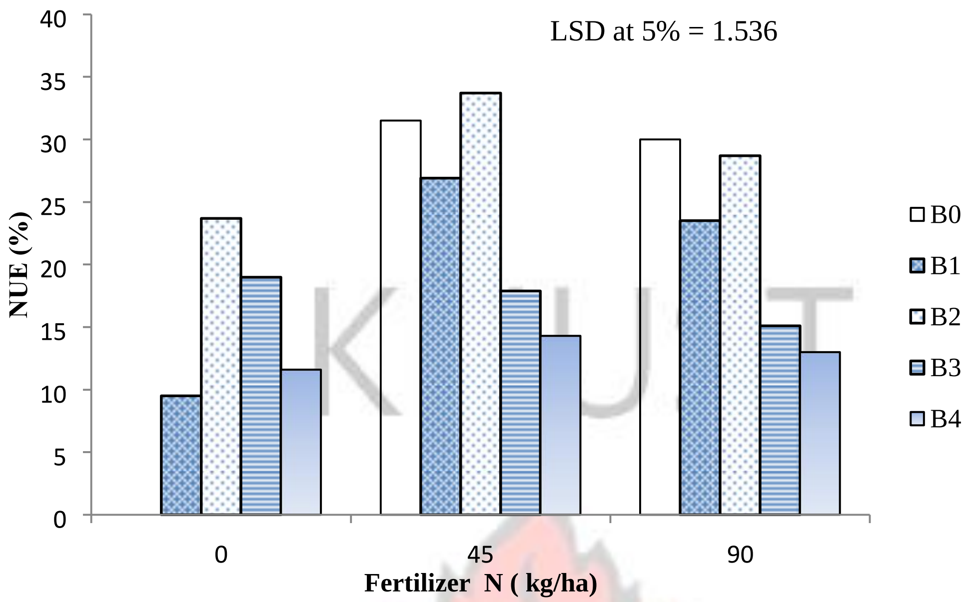


Figure 4.14: Effects of biochar and inorganic N fertilizer application on NUE of maize in the major cropping season of 2013. BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 t ha^{-1} respectively. Data points are the means of 3 replicates. LSD = Least Significant Difference.

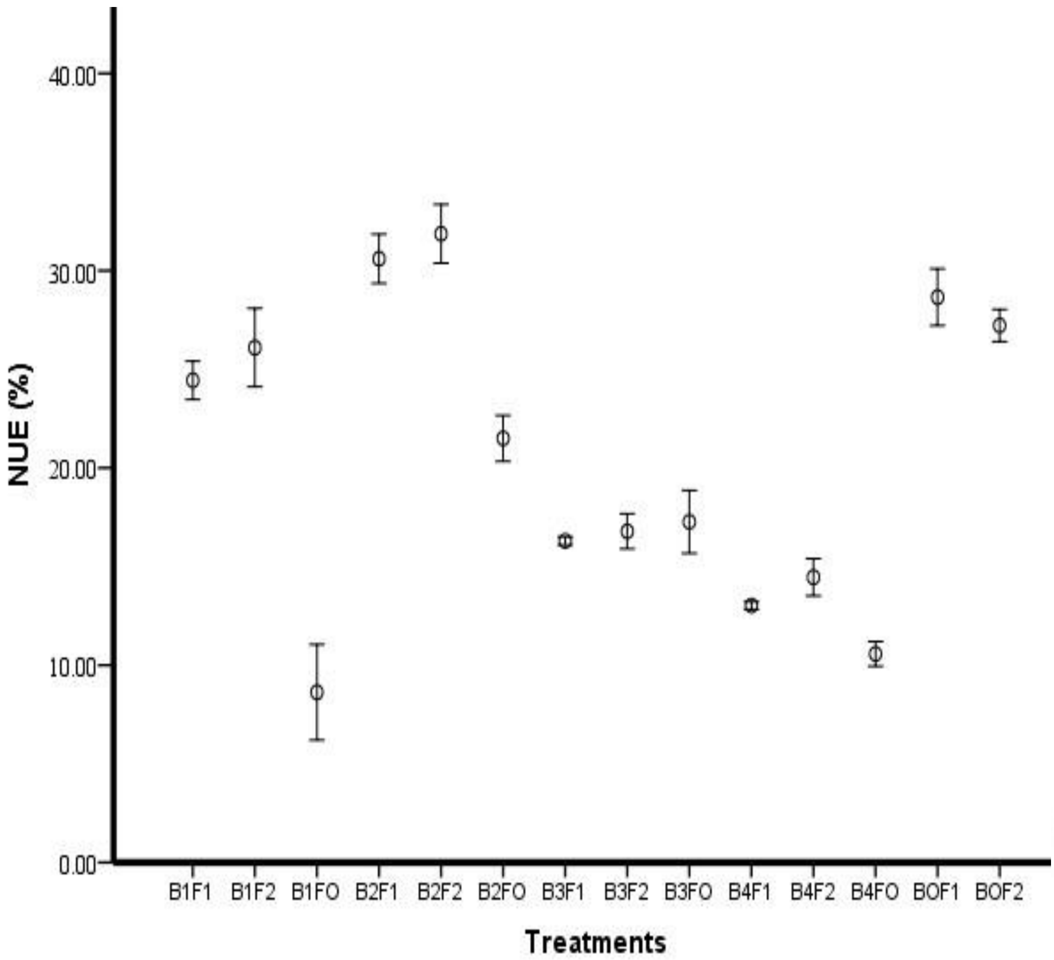


Figure: 4.15 Dotplot showing the mean nitrogen use efficiencies (NUE) of maize as affected by biochar and fertilizer N treatments during the minor and major cropping seasons. BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 t ha^{-1} respectively. FO, F1 and F2 are fertilizer N treatments applied at 0, 45 and 90 kg N ha^{-1} respectively. Data points are the means of 3 replicates. Error bars are standard errors of means.

CHAPTER FIVE

DISCUSSION

5.1 Chemical Composition of Biochar

With a low N content, biochar recorded a high C/N ratio which was beyond the critical maximum of 30: 1 (Troeh and Thompson, 2005). The results on biochar chemistry showed that the application of biochar could result in initial N immobilization considering its wide C/N ratio and/or N-adsorption to the biochar pore system (Palm et al., 2001). In addition, the chemical characteristics of the biochar revealed it might be limited as a sole soil nutrient booster except supplementary nutrient sources from inorganic or organic fertilizers are applied (Partey et al., 2014).

5.2 Effects of biochar and inorganic N fertilizer on Soil Properties

The initial soil test results showed the soil at the research site was relatively low in nitrogen and has limited capacity for high nutrient retention as revealed by CEC. This is typical of most African soils which necessitate the application of inorganic fertilizers or other viable nutrient sources. Many scientists have reported that the application of biochar may augment soil properties for improved soil productivity (Sohi et al., 2010; Laird et al., 2010; Lehmann et al., 2006). The results of this study showed the application of biochar either solely or with inorganic fertilizer N increased the N availability of the soil at the study site. While sole biochar application increased N availability, the results may be attributed to possible priming effect from existing organic matter in the soil rather than N supply from the mineralization of the biochar itself. With a mean resident time of 100 – 1000 years, the recalcitrant nature of biochar has been widely reported (Verheijen et al., 2010). The review by Sohi et al. (2010) showed that the application of biochar could cause N flush due to the effect on microbial decomposition of exiting organic matter. Increased N availability with combined biochar and N fertilizer application has been reported (Asai et al., 2009; Chan and Xu, 2009) and the finding of this study is consistent with those reports. The highest effect of biochar applied at 10 t/ha and fertilizer N applied at 90 kg/ha (B2F2) on mineral N is supported by other studies. Lehmann et al, (2003) and Nelson et al. (2011) have reported increased mineral N and other soil fertility indicators with a combined biochar and fertilizer application at 10 t ha^{-1} biochar and 90 kg N ha^{-1} inorganic N fertilizer. While other studies showed that biochar application of up to 50 t ha^{-1} may improve soil fertility (Sohi et al., 2010), the results obtained showed biochar applied at 10 t ha^{-1} could be best for the soils at the study location. The review by Verheijen et al. (2010) showed that soils may show varying responses to biochar and that the effect of different biochar products may also show varying effects on different soil types.

The increased soil mineral N in the biochar and fertilizer N interaction may be due to potential reduction in nutrient leaching and increased nutrient holding capacity of the soil (Partey et al., 2014). Although nutrient leaching was not covered in this research, it has been shown to reduce with biochar application even on highly weathered soils (Laird et al., 2010; Steiner et al., 2008). The increased CEC observed with biochar addition confirms the soil‘s interactive ability and adsorption for available minerals and cations. Increased CEC with biochar application is well known (Jeffery et al., 2011; Sohi et al., 2010). The improvement in CEC with biochar application is crucial in many areas of the humid and sub-humid tropics dominated by soils of low cation exchange capacity, the so-called low-acidity clay soils that may quickly lose their fertility if fallow periods, or some analog to fallow conditions, are not imposed (Kang, 1991).

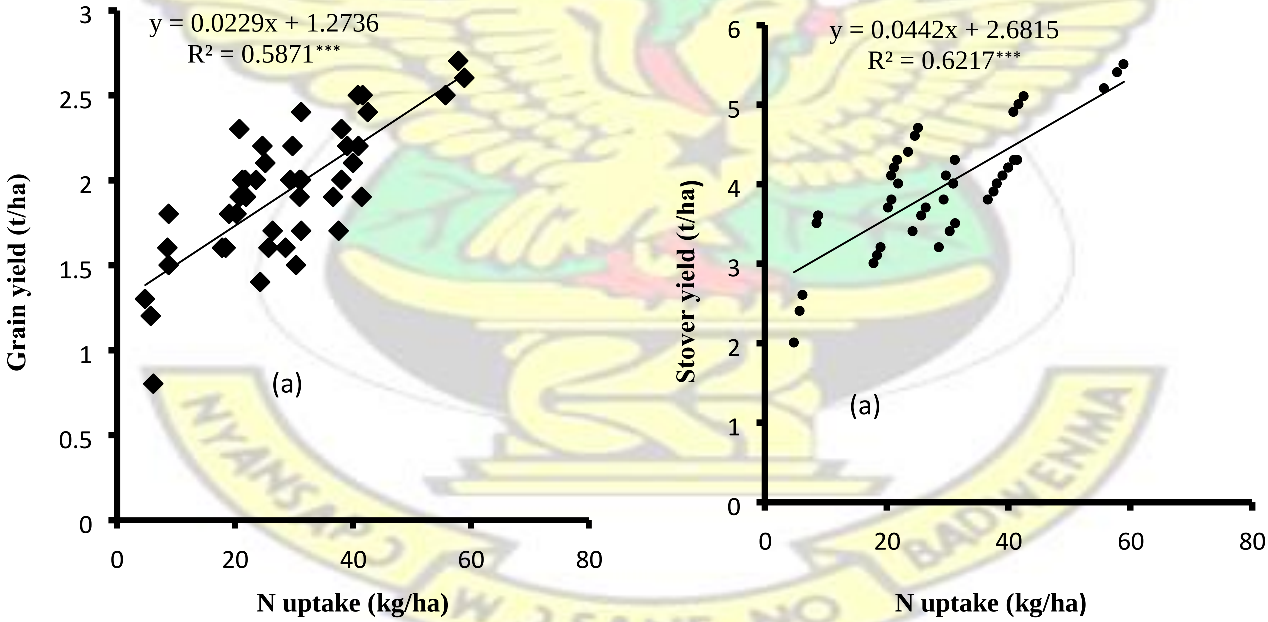
5.3 Effects of biochar and inorganic N fertilizer application on crop performance

While the application of fertilizers alone could boost crop productivity levels, the increase in yield observed with combined biochar and inorganic fertilizer N implied the synergistic effects of organic and inorganic nutrients. Relative to crops that received the highest fertilizer rate (90 kg N /ha), total grain and shoot yields were 76% and 128%, respectively, greater on plots that received 10t/ha biochar plus 90kgN/ha. This observation confirmed biochar use as an important resource for smallholder agriculture. Previous studies also found high responses of maize and other cereals to fertilizers and biochar amendments (Asai et al., 2009; Partey et al., 2015; Zhang et al., 2012), which are consistent with the observations made in this study. It has been well documented that the application of biochar on croplands enhances crop productivity through improving soil quality (Asai et al., 2009; Gaskin et al., 2010; Haefele et al., 2011; Major et al., 2010a; Sohi et al., 2010; Zwieten et al., 2010). In this study, soil mineral N and CEC were found to be greatest on biocharamended plots compared with un-amended plots.

Apart from increased N, the greater biological yield of maize recorded on biocharamended soils can be attributed to the improved nutrient uptake and NUE. The results showed biochar application increased N uptake by about 200% compared with unamended plots. In addition, significant positive correlations were observed between nutrient uptake and shoot and grain yield of maize (Figure. 5.1), which attest to the dependence of biological yield of maize on nutrient uptake. Increased N uptake in crops with biochar application is well documented (Chan et al., 2008; Major et al., 2010b) and has been related to the reduced nutrient leaching and improved CEC associated with biochar application (Laird et al., 2010; Sohi et al., 2010; Steiner et al., 2008).

The overall results of soil fertility assessment and crop performance put some treatment pairs as having similar performance based on a hierarchical cluster analysis (Figure. 5.2). Fertilizer N at 45 kg/ha with no biochar (BOF1) and biochar at 5 t/ha with no fertilizer (B1FO) showed similar performance. Biochar at 20 t/ha with either fertilizer

N at 45 kg/ha or 90 kg/ha were also similar (B4F1 and B4F2). Again biochar at 20 t/ha and biochar at 10 t/ha with no fertilizer (B4FO and B2FO) showed similar performance. Likewise treatment pairs with similar performance were biochar at 15 t/ha with either fertilizer N at 45 kg/ha or 90 kg/ha (B3F1 and B3FO) and biochar at
10 t/ha with either fertilizer N at 45 kg/ha or 90 kg/ha (B2F1 and B2F2) (Figure. 5.2). As shown in Figure 5.2, control (BOFO) was least similar to all the treatments. In addition, the cluster puts biochar at 10 t/ha with either fertilizer N at 45 kg/ha or 90 kg/ha (B2F1 and B2F2) as best treatment as they are significantly different from the rest. Considering that biochar at 10 t/ha and fertilizer at 45 kg N ha^{-1} (B2F1) and same biochar rate but higher fertilizer, 90 kg N/ha (B2F2) recorded similar effects, it will be more profitable using fertilizer at 45 kg N ha^{-1} which could be relatively less expensive compared with applying 90 kg N ha^{-1}



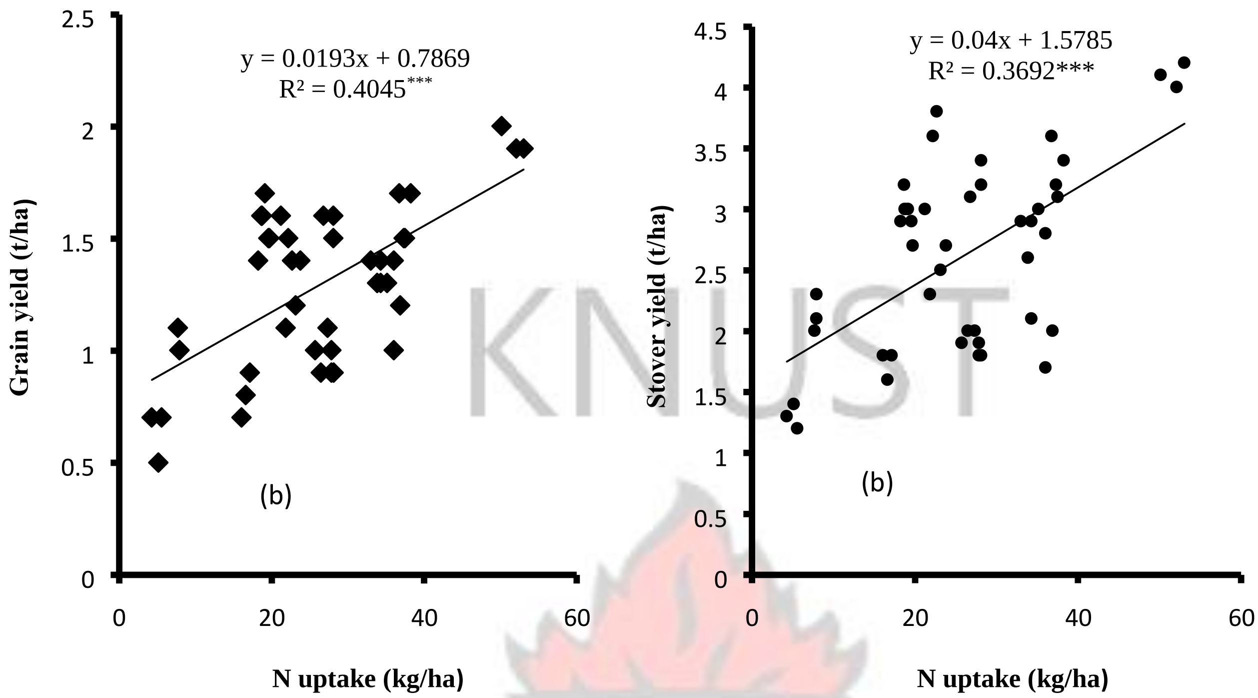


Figure 5.1: Relationship between nitrogen uptake and stover and grain yield of maize as affected by biochar and inorganic N fertilizer treatments during the major (a) and minor (b) cropping seasons. * = significance at P = 0.001. N = 45**

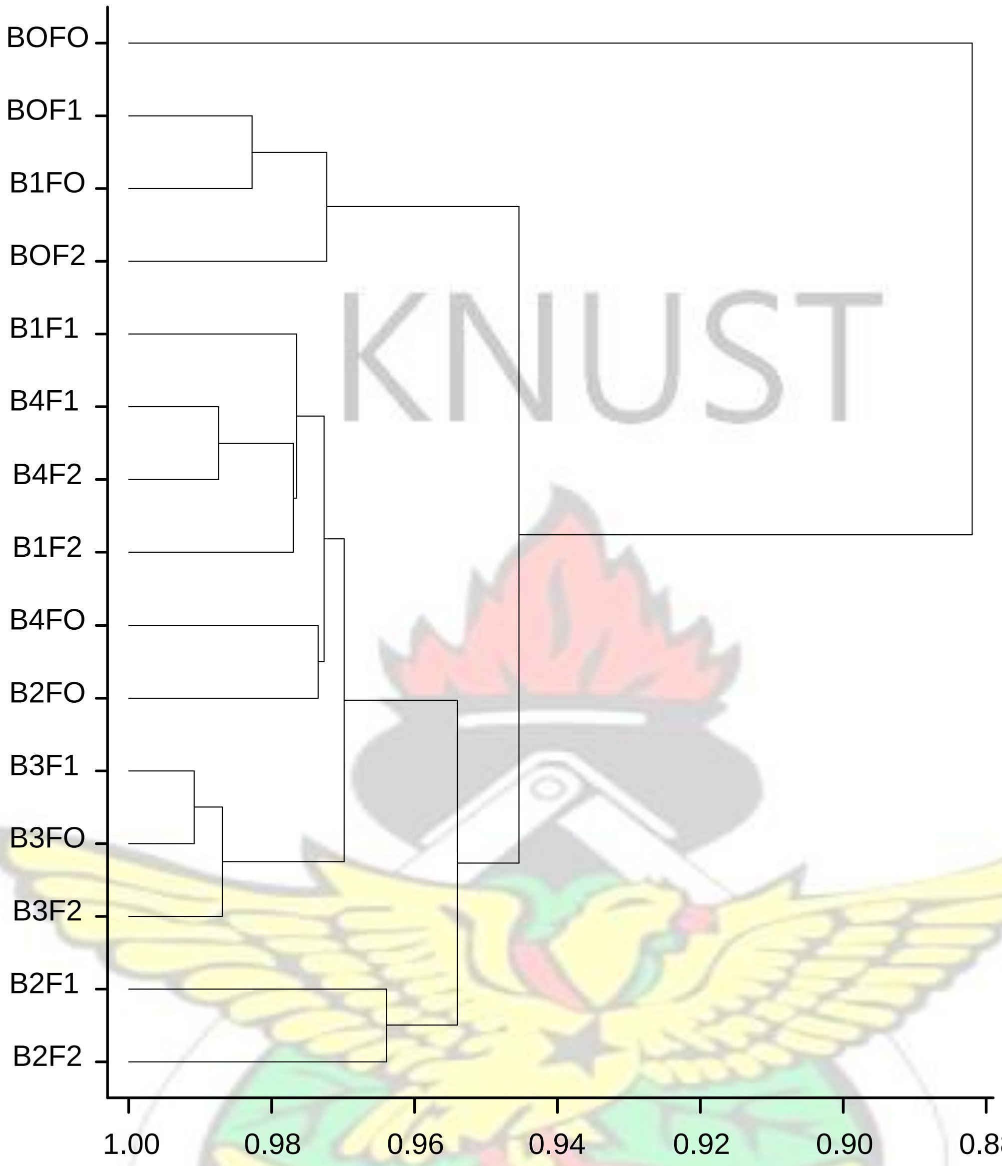


Figure 5.2: A dendrogram showing similarities in the overall performance of biochar and fertilizer treatments. BO, B1, B2, B3 and B4 are biochar amendments applied at 0, 5, 10, 15 and 20 t ha^{-1} respectively. FO, F1 and F2 are fertilizer treatments applied at 0, 45 and 90 kg N ha^{-1} respectively.

Similarity matrix was formed using the effects of treatments on CEC, pH, mineral N, grain and stover yields for both minor and major cropping seasons; and N uptake recorded for both minor and major cropping seasons.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

The results of this study demonstrated that the application of fertilizers may improve soil fertility and increase crop yields but their effects may be higher when applied with biochar (particularly at 10 t ha^{-1}) in the study area. Throughout both cropping seasons, biochar-amended plots recorded significantly higher grain yield relative to un-amended plots. While the response of soil properties and crops may differ with biochar produced from different feedstocks, soil conditions and geographical region, the results of this study points to the fact that biochar could be an important resource for resource-poor farmers within the study area. However, the large quantities of feedstock required and the cost of production may limit the adoption of biochar in smallholder agroecosystems. There is therefore the need to test the wider applicability of biochar across various agroecozones and compare costs and benefits to influence the adoption and use of biochar in African cropping systems.

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