EFFECT OF RICE HUSK BIOCHAR ON MAIZE PRODUCTIVITY IN THE GUINEA SAVANNAH ZONE OF GHANA

By

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DECLARATION

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

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DEDICATION

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ABSTRACT

The production and use of biochar presents many opportunities for soil augmentation and carbon sequestration. The potential of biochar as a carbon pool has the ability to sequester carbon in soils and consequently reduce atmospheric concentration of greenhouse gasses. Maize and rice are staple crops produced in Northern Ghana. There is significant biomass available as potential feedstock for biochar production such rice husk, maize stover and cobs; however how much of these residue that could be used for biochar is not documented. The objective of this study was therefore to identify the types of feedstock, the opportunity cost of potential biochar feedstock, some chemical properties of the biochar produced from the rice husk and the effect of the biochar on the growth and yield of maize (*Zea mays*). The trial consisted of 12 treatments in a split plot experimental design. The main factor is rate of biochar application (0, 2 and 4 t/ha) and the sub-plot was rate of nitrogen application (0, 30, 60 and 90 kg N/ha) with three replications. Sufficient quantities of P and K were applied as basal at 30 kg and 60 kg / ha respectively to ensure that none of these nutrients limited yield. Phosphorus and K were broadcast and incorporated at planting. Phosphorus source was triple superphosphate and the K source was muriate of potash. The data was analyzed with GenSTAT 2008 and where the effect was significant the least significant difference (LSD) was used to separate the means. The survey indicated that the potential feedstock available are maize stover, maize cobs, groundnut shell, rice husk, rice straw, shea nut shell, guinea corn stover and cowpea shell. The opportunity cost of using this potential feedstock for biochar preparation is low. Generally, trend of soil moisture content increased with the rate of biochar application in the order control < 2t/ha biochar < 4t/ha biochar. The application of biochar with inorganic fertilizers increased maize biomass production. Maize plant height and girth were increased significantly when biochar and inorganic N were applied. The yield obtained by combination of biochar and

inorganic fertilizer was in significantly higher than the sole application of either biochar or inorganic fertilizer. The soil pH at the end of the experiment increased in all the treatments. Soil total N, % C and ECEC increased within all the treatments. Application of biochar resulted in less than 30% N recovery in the grain, husk and cob with all the treatment combinations. The addition of biochar 2t/ha and 4t/ha increased the grain yield and improved water use efficiency of the maize crop. Biochar can be used as a component in integrated soil fertility management to increase crop productivity.

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1.0 INTRODUCTION

1.1 Background of the study

It is approximated that in Africa about fifty-five percent (55%) of the land area is unsuitable for agriculture production. Merely 11% has high-quality soil that can successfully be managed to sustain more than twice the existing population over numerous countries, (Eswaran *et al.*, 1997). Most of the usable land is of medium or low potential, with at least one major limitation for agriculture. This might result in high threat of degradation under low input farming systems. Forty–three percent (43 %) of Africa is dry lands (arid, semi-arid, and sub-humid arid zones) impacting 485 million people (Reich *et al.*, 2001). Just about 65% of agricultural land, 31% of permanent pastures and 19% of forest and woodland in Africa were approximated to be affected by some form of degradation (Oldeman, 1994). The current position is undoubtedly worse. Moisture stress essentially constrains land productivity on 86% of soils in Africa (Eswaran *et al.*, 1997). Soil fertility degradation now places an additional serious human-induced restriction on productivity. Agricultural systems with inadequate nutrient input on land with poor to moderate potential are the rationale behind human-induced soil degradation in Africa. Although many farmers have developed strategies to manage soils to cope with the poor quality, low inputs of nutrient and low soil organic matter constitutes to poor crop growth and the soil nutrient depletion. The use of fertilizer all over the continent is by far the least in the world, below 9 kg N/ha and 6 kg P/ha, in contrast with typical crop requirements of 60 kg N/ ha and 30 kg P/ ha. Mid-1990s approximations confirm that every country in Africa had a negative nutrient balance in its soils, in that the quantity of N, P and K added as inputs was extensively less than the quantity removed as harvest, or lost via erosion and leaching.

Soil fertility decline is coupled with numerous simultaneous degradation processes feeding on each other to produce a descending curve in productivity and environmental quality. For instance, the collective effects of tillage and inadequate applications of nutrient and organic matter predictably lead to a decline in soil organic matter. This decreases the retention of crucial plant nutrients, breaking down soil physical structure and in turn declining water infiltration and the water storage capacity of the soil. Apart from this, African farmers face other degradation processes such as erosion, salinization and acidification (Oldeman, 1994).

In sub-Saharan African (SSA) countries, the decline in soil fertility is attributed essentially to continuous cultivation, coupled with quick organic matter mineralization (Dovanan and Casey, 1998). Generally agricultural systems in Ghana are categorized by low productivity, due to unreliable rainfall patterns, obsolete agricultural practices and low application of inputs. It is approximated that soil fertility loss via erosion could reduce agricultural income in the country by US$ 4.2 billion and could additionally cause a 5.4 % increase in the poverty rate during the period 2006–2015 (Quaye *et al.,* 2010).

Approximately 57 % of the economically active population in Ghana are engaged in agricultural activities, chiefly as smallholder subsistence food crop farmers for their livelihoods. Food production is principally through the extensive system of shifting cultivation in which farmers “slash and burn” a piece of land, grow food crops in polyculture for 1–3 years and leave it to fallow. This form of agricultural practice causes rapid reduction in forest cover and land degradation. Though, the shifting cultivation system assists restoration of soil fertility, the improvement in reduction in the fallow period as a result of increasing population pressure makes it implausible for these soils to recover high levels of fertility (Quaye *et al.,* 2010).

In Ghana, employed strategies for improved agricultural productivity include the use of inorganic fertilizers. However, the potential of this strategy is low due to problems of affordability and accessibility by smallholder farmers (Yeboah *et al.*, 2009).

Currently it is approximated that 60 % of the people are engaged in agriculture in Tamale Metropolis. The major crops cultivated include maize, rice, sorghum, millet, cowpea, groundnuts, soya bean, yam and cassava.

Nevertheless the trend of growth started declining as a result of the removal of subventions on agricultural inputs, rapid population growth, declining soil fertility and the gradual decrease in the land area as a result of the rapid expansion of Tamale (Ghana district, 2012).

Biochar is charcoal formed from the thermal decomposition of biomass in a low- or zero-oxygen environment, at moderately low temperatures (<700°C) (Lehmann and Joseph, 2009). Biochar application to soils is presently attaining universal attention due to its potential to improve water holding capacity, soil nutrient retention capacity, and sustainable carbon store, thus reducing greenhouse gas emissions (Downie *et al.,* 2009). Biochar's capacity to concurrently act in both soil modification and as a carbon sequestration medium afford a win-win prospect that could help decrease atmospheric carbon dioxide in the near future (Amonette and Joseph, 2009).

Biochar has the potential to increase the availability of plants nutrient (Lehmann *et al.*, 2008). Availability of nutrients can be influenced by increasing Cation Exchange Capacity (CEC), transformed soil pH, or immediate nutrient contributions from biochar. The potential mechanism for improved nutrient retention and supply subsequent to biochar modification was increasing CEC up to 50% as compared to unamended soils (Mbagwu and Piccolo, 1997). Biochar has a greater capacity to absorb and retain cations in an exchangeable compared to than other forms of soil organic matter owing to its greater surface area, and negative surface charge (Liang *et al.*, 2006).

The application of biochar to soil is not a new concept. Pieces of black soil originated in the Amazon Basin (so-called Amazonian Dark Earths or "*terra preta*") appear to have been enclosed with large quantities of residues from biomass burning (Sombroek *et al.*, 2003). These applications were most probably a result of both habitation activities and conscious soil application by Amerindian populations before the arrival of Europeans (Lehmann *et al.*, 2006). Today large quantities of biochar-derived C stocks remain in these soils, hundreds of years after they were deserted. The total C storage is additionally twice as high in contrast to Amazonian soils without biochar (Glaser *et al.*, 2001). Whereas biochar ultimately mineralizes in soils, a fraction of it is left in a very stable form. These properties of biochar provide it with the potential to be a key carbon sink. Contrasted with other terrestrial sequestration strategies, such as afforestation or re-forestation, carbon sequestration in biochar increases its storage time (Marris, 2006).

According to Moses *et al.,* (2011) biochar production and application in soils has a very high potential for the expansion of sustainable agricultural systems in Ghana, and also for global climate change mitigation. There is significant biomass availability in the country as potential feedstock for biochar production such as rice husk, maize stover, corn cob e.t.c. Northern region has a potential of crop residues available, and nonetheless how much of these residue could be used for biochar is not documented. Farmers have alternative uses for crop residue e.g. for fuel, fencing, roofing e.t.c However, to support the application of biochar as a soil amendment and also as climate change abatement alternative, a baseline study embracing the compilation and analysis of data on biomass resources including types and ease of collection and the opportunity cost of this potential feedstock in Ghana needs be conducted.

1.2 Statement of the problem

The decline in soil productivity due to continuous cultivation in Sub-Saharan Africa has been acknowledged as one of the main causes of food insecurity and poverty. Crop yields continue to diminish on smallholder farmers fields and there is a huge gap between potential crop yields and actual crop yields. To achieve food adequacy, there is the pressing need to manage the soil infertility problem. Additionally, improving crop productivity on these soils is essential for socio-economic reasons. Numerous interventions have been considered in the past but with little success. Although the application of inorganic fertilizers provides an alternative to overcome soil infertility, the removal of fertilizer subsidies has resulted in relatively higher fertilizer prices and thus inaccessible to many smallholder farmers.

1.3 Justification

Over 70% of Africa's poor live in rural areas, a pattern that is likely to continue for several years. The rural poor derive majority of their livelihood from agriculture, thus increasing agricultural productivity is vital for significant poverty reduction. Food insecurity, a primary determinant of poverty, is one of the main problems facing the continent. Whereas per capita food availability in the world has improved significantly over the past 45 years, the condition in SSA has improved only a little. For instance, the average cereal yield is still less than 1 tonne per hectare in SSA, and the continent-wide average yield has increased insufficiently by 5.2 kg ha^{-1} y^{-1} over the past 33 years (FAOSTAT, 2005).

The Northern region of Ghana is considered as one of the bread basket regions of the country with a total land area of 38,352 hectares under cultivation (Ghana District, 2012). Presently it is estimated that about 60% of the people in the Tamale metropolis are engaged in agriculture. Owing to high agriculture activities in the Tamale metropolis large quantities of crop residues such as the rice husk is left unused. Although some of these crop residues have alternative uses among farmers, there is no documentation on how much crop residues are available and could be used for biochar and how much of these are used for other purposes.

Biochar management may supply a significant opportunity for sustainable enhancement of soil fertility owing to its elevated stability. Therefore, the objective for this study was to investigate the availability of rice husk residue for biochar preparation and short-term effects of rice husk biochar on soil fertility and maize productivity in Northern region.

The study also determines the physical and chemical properties of the rice husk feedstock and the biochar from the rice husk feedstock and the opportunity cost of potential biochar feedstock.

1.4 Research hypothesis and specific objectives

The study hypothesized that rice husk biochar with or without inorganic fertilizer nitrogen application can increase maize productivity in the Guinea savannah zone of Ghana.

The specific objectives are:

1. To identify and document the types of feedstock available for biochar preparation
2. To determine the opportunity cost of potential biochar feedstock
3. To determine the chemical properties of the char produced from the rice husk
4. To determine the effect of the rice husk biochar on maize growth and yield

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

As population increase soil-nutrient capital is steadily depleted when farmers are incapable to adequately recompense losses by returning nutrients to the soil via crop residues, manures and mineral fertilizers. Increasing demands on agriculture lands has resulted in greater nutrient outflows and the consequent breakdown of several traditional soil fertility maintenance strategies. This traditional fertility maintenance strategies for example intercropping cereals with legume crops, manure producing mixed crop-livestock farming, fallowing and opening new lands have not been replaced by an effective fertilizer supply (Sanders *et al.*, 1996). Numerous decades of nutrient reduction have changed originally fertile lands that yielded about 2 to 4 t ha^{-1} of cereal grain into infertile ones where cereal crops yield less than 1 t ha^{-1}. For instance, in Kenya long-term trials in Kabete, signified that fertile soil lost about 1 t ha^{-1} of soil organic N and 100 kg P ha^{-1} of soil organic P throughout 18 years of continuous maize (*Zea mays*) – common beans (*Phaseolus vulgaris*) cultivation without nutrient inputs, amid maize yields decreasing from 3 to 1 t ha^{-1} throughout that period (Qureshi, 1991; Swift *et al.*, 1994; Kapkiyai *et al.*, 1997).

In Africa greater part of the food produced are on smallholder farms (Cleaver and Schreiber, 1994; Gladwin *et al.*, 1997). One of the vital problems affecting food production in Africa is the speedy reduction of nutrients in smallholder farms (Badiane and Delgado, 1995). This relies on the information that smallholder farmers are poorly resourced and incapable to empower soil fertility inputs, predominantly mineral fertilizers. This demonstrates to the fact that about half of Africa's population is categorized as "absolute poor" surviving on per capita incomes of less than 1 US$ per day (Badiane and Delgado, 1995).

The key effect of soil fertility decline in most African countries is the reduced food production including Ghana. Optional soil fertility replenishment strategies should be explored which are effective and reasonable to farmers, particularly the smallholder farmer in order to sustain soil and crop productivity.

Biochar has been illustrated as the recent day equivalent to the Terra Preta-dark earth-soils of the Amazon and has been tagged a key factor in the global carbon mitigation act (Sohi *et al*., 2009). The production of the char material has three (3) major rationale in the economy as positioned: charcoal-briquette production for cooking, activated char used in the metallurgical industry, and as a future soil modifying agent to assist mitigate carbon dioxide (CO_2), namely biochar (Sims, 2002).

The following significant question arises: how realistic is the application of biochar in agricultural practices and what is the long term impact on the environment?.

According to Sims (2002), biomass is defined as current organic matter originally derived from plants as a result of the photosynthetic conversion process, or from animals, and which is destined to be used as a store of chemical energy to provide electricity, heat, or transport fuels. There are numerous forms of biomass, as mentioned to simplify the idea one can identify biomass as a potential fuel.

The worth of this fuel is exposed when the stored chemical energy is released *via* pyrolysis, gasification, combustion and biochemical processes e.g. fermentation. Biomass and its use can be observed to fuel primary energy conversion technology (Sims, 2002).

2.2 Biomass availability

The accessibility of large quantities of biomass feedstock and the transportation distance to a pyrolysis plant are critical considerations for an efficient and economically feasible biochar production system (Roberts *et al.*, 2010).

Lehmann *et al.*, (2006) showed that olive, tobacco, nut shells and bagasse waste are all extremely appropriate feedstocks owing to location of farms and their existing processing facilities due to the huge biomass quantities produced. Such as, bagasse production in Queensland is about 12 million tons annually (Krull, 2009).

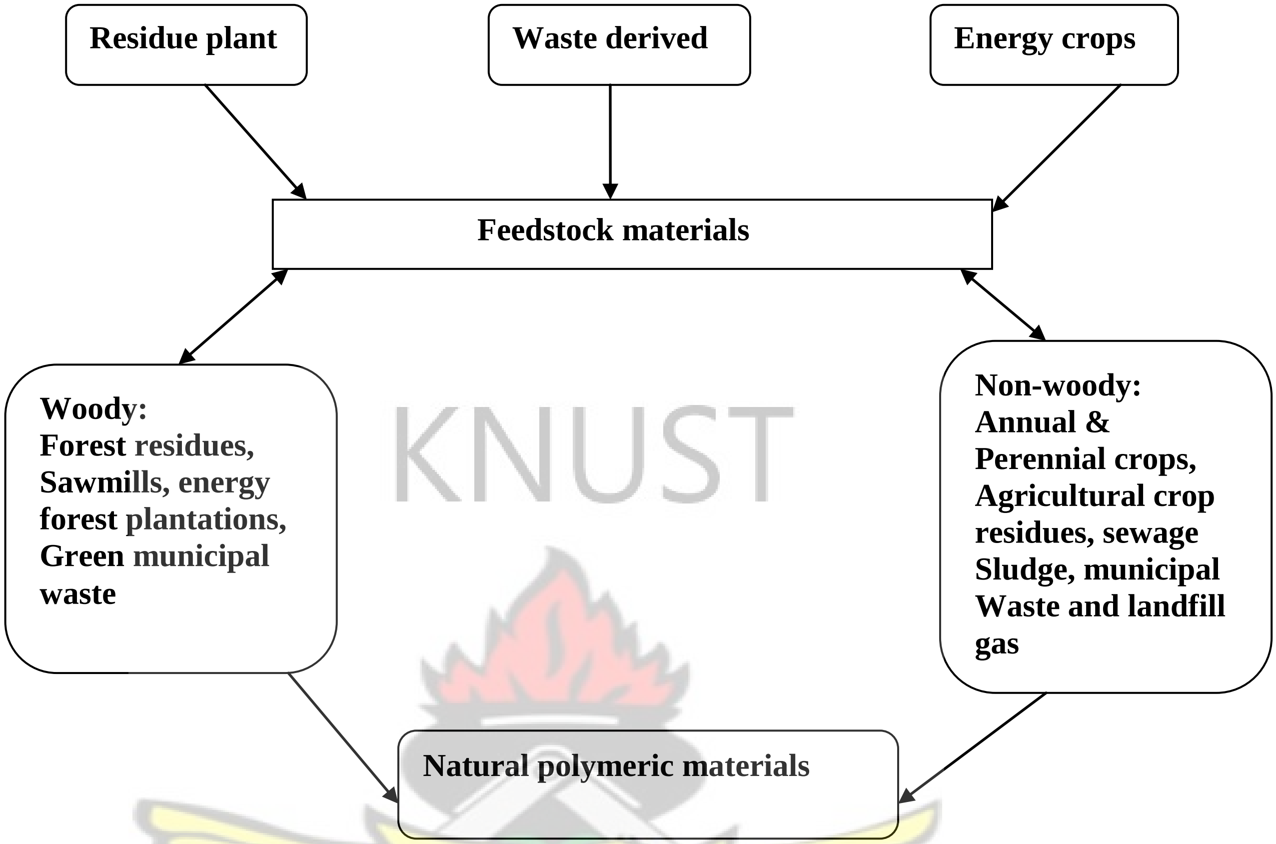
It is likely to co-locate pyrolysis plants with biomass processing operations to reduce handling costs and supply a waste management solution. Production of biochar has the potential to be leveled to any point of production based on location and feedstock quantities and quality.

2.3 Feedstock resources

Biomass can be generally classified as woody- and non-woody feedstock which will only serve as an introduction to potential feedstock resources. Woody biomass of plant materials comprise chiefly hemicelluloses, cellulose and lignin, and it thus vary from other biomass materials e.g. agricultural/ horticultural crops, sludges and some municipal waste (Sims, 2002). Average trees have about 20% to 30% lignin, and lignin has approximately twice the heat value of cellulose. Source of woody biomass are from resources such as residues from wood processing activities (sawmills), energy forest plantations (purposeful grown), forest residues and green municipal waste (Zeelie, 2012).

The suitability of a particular biomass as a potential feedstock for biochar production depends various characteristics such as ash content, moisture content, fixed carbon, hydrogen, nitrogen, oxygen, volatiles, cellulose/lignin ratio and calorific value (McHenry, 2009).

Non-woody biomass have the prospective to afford both rural and urban areas with renewable energy, principally since there's a selection of biomass resources, such as energy crops (both annual- and perennial varieties), agricultural crop residues, sewage sludge (both anthropogenic- and/ or animal-derived wastes), landfill gas and municipal wastes (Zeelie, 2012).



Source: Zeelie, (2012)

Figure 2.1. Categorized feedstock materials

2.3 Biochar quality

Biochar can be produced from any biomass feedstock, it is vital to develop quality standards to guarantee non-toxic biochar is produced sustainably. According to Kwapinski *et al.*, (2010) feedstocks should be leveled based on their suitability for biochar production for the application of agricultural soil and guidelines should also be developed to ensure ample planning of feedstock use. Feedstock type and pyrolysis conditions influence the physico- chemical characteristics of biochar. Owing to the range of biomass alternative and pyrolysis systems available biochar production is high.

This has major implications for nutrient availability and nutrient content of biochar to plants when applied to soil (Downie *et al.*, 2009).

2.4 Ash content

Biochar ash content has inorganic constituents e.g. calcium, magnesium and inorganic carbonates when all organic elements (nitrogen, carbon and hydrogen) is volatilised (Joseph *et al.*, 2009). The pyrolysis conditions and feedstock source demonstrate to affect the inorganic ash content of biochar, which in line might affect potential end uses (Kookana *et al.*, 2011). Generally woody feedstocks can produce char with low ash content (less than 1 per cent), whereas some straws and grasses are high in silica and can produce up to 24 per cent ash in the char (Joseph *et al.*, 2009). Nevertheless, under certain processing conditions and when feedstock has high silica content, the resulting biochar has the potential to cause silicosis in humans; suitable precautions (such as face masks) should thus be used (Shackley and Sohi 2010).

Bagreev *et al.*, (2001) stated ash content to increase from 61.7 per cent to 76.8 percent when sewage sludge was heated up to 400^{o}C and 800^{o}C, respectively. Singh *et al.*, (2010) also established that increase in the pyrolysis temperature caused ash content of various biochars to decrease. This tendency was most obvious when paper sludge was used as the feedstock.

2.5 Structural characteristics

The structure of biochar can manipulate some of its quality characteristics. The porosity and surface area of biochar are mainly significant and consist of a large role in determining its potential end use. The initial macrostructure of a feedstock is comparable to that of the resulting biochar and this is predominantly the situation for plant materials that are high in cellulose (Sohi *et al.,* 2010).

Pyrolysis removes largely volatile compounds; the macrostructure of the biomass are retained in large extent in the biochar. Conversely, structural tension causes cracks in the macrostructure, and the escape of volatilised gases causes smaller pores to open in the material (Downie *et al.,* 2009). The porosity and surface area of biochar in different pyrolysis temperatures has potential major effects on adsorption, water holding capacity and nutrient retention ability (Sohi *et al.,* 2010).

Bagreev *et al.,* (2001) demonstrated that increase in porosity and thus surface area of biochar is associated to the temperature of pyrolysis. Boateng (2007) established that the surface area of biochar produced was low using switch grass; varying from 7.7 to 7.9 square metres per gram.

Another study stated related initial results, however demonstrated that biochar surface area increased by a factor of three when the pyrolysis temperature increased from 400 to 950^{o}C (41 to 99 square metres per gram, respectively) (Bagreev *et al.,* 2001).

These results and that of Keiluweit *et al.,* (2010) revealed a broad tendency of increasing surface area of biochars with increasing pyrolysis temperatures. Keiluweit *et al.,* (2010) also showed increasing porosity and thus surface area is coupled with a decline in the total carbon and volatile matter. Although the mechanisms of increased water holding capacity of soils altered with biochar are not understood, it is well recognized that the surface area of soil particles strongly manipulates its water holding capacity; sand seize little water and clay holds a lot. The addition of biochar to soils increases surface area and may have an impact on water holding capacity. It is generally established that biochar have a tendency to infiltration rates of some soils and to increase water adsorption capacity, as reported by some researchers that some biochars produced at low temperatures (400^{o}C) may be hydrophobic, which might limit their effectiveness to store water (Day *et al.,* 2005).

Low conditions in temperature via pyrolysis might produce biochars suitable for use as a nitrogen fertilizer substitute (Day *et al.*, 2005), when biochars produced at high temperatures suitable to adsorption activities e.g. reducing heavy metal contamination in soils (Sohi *et al.*, 2010).

In contrast, Boateng (2007) showed that biochars formed at 480^{o}C had poor adsorption characteristics devoid of additional activation. Moreover, it has been established that biochar formed at low temperatures are brittle and prone to abrasion (Day *et al.,* 2005). As such, the surface area and porosity of biochar might not influence the quality of the product over the long term.

2.6 Ion exchange capacities of biochar

The nutrient retention power of biochar depends on their cation and anion exchange capacity (Chan and Xu 2009). Cations (positively charged ions) and anions (negatively charged ions) are attracted to opposite charge. Mineral nutrients of plant e.g. calcium, potassium, phosphorus, and nitrogen are in soil water (soil solution); primarily as cations and anions in some cases. Small particles in soils e.g. humus and clay, carry negative charges and thus attract cations, as anions are comparatively free to travel in the soil solution and both freely available for uptake by plants and for leaching. Cation exchange capacity ascertain the soil's capacity to seize cations and the higher the cation exchange capacity the more fertile the soil.

Biochar has an appreciable anion exchange capacity and can thus adsorb anion nutrients (such as phosphate and nitrate) when they are incorporated into simple organic molecules. Researchers have revealed that biochar produced at low temperatures have a high cation exchange capacity, as those produced at high temperatures (greater than 600^{o}C) have inadequate or no cation exchange capacity (Chan *et al.*, 2007). These results would recommend that biochar for soil modification should not be produced at high temperatures. Furthermore freshly formed biochar have little cation exchange capacity, whereas their anion exchange capacity is substantial CEC (Chan *et al.*, 2008; Lehmann et al., 2008). Whiles biochar matures or ages in the soil, its cation exchange capacity increases (Liang *et al*., 2006).

Biochar with high cation exchange capacity have the capability to absorb heavy metals and organic contaminants e.g. pesticides and herbicides from the environment (Navia and Crowley 2010). The addition of biochar to agricultural soils as soil ameliorant is predicted to adversely influence the efficacy of agrochemicals e.g. herbicides and pesticides (Jones *et al*., 2011).

2.7 Nutrient content of biochars

In general, biochar nutrient content reflects the nutrient content of the feedstock.

Biochar formed from manure is relatively high in nutrients, especially phosphorous.

Biochars produced from plant material and those produced from wood commonly have low nutrient levels and those formed from leaves and food processing wastes have higher nutrient levels. Pyrolysis conditions also influence availability and nutrient content. High pyrolysis temperatures could decrease nitrogen content and availability. Bagreev *et al.*, (2001) has established that total nitrogen decreased from 3.8 to 1.6 per cent when the pyrolysis temperature increased from 400 to 800^oC.

Another study by Lang *et al.*, (2005) stated related effects on the nitrogen content in both woody and herbaceous char: nitrogen was steadily released from the char samples, starting at 400^oC and continuing to 750^oC, which was slightly more than half the initial nitrogen remained.

In addition to partial loss of nitrogen, a decrease in availability of the residual nitrogen to plants was also established. The remaining nitrogen becomes integrated into the carbon matrix, preventing the availability of nitrogen in the biochar produced (Bagreev *et al.*, 2001). The conditions of the pyrolysis and biomass feedstock influence both the composition and structure of biochar, resulting in major differences in nutrient content.

Furthermore, the difference in the physico-chemical nature of biochars causes variability in the availability of nutrients within each biochar to plants. Biochars resulting from manure and animal-product feedstocks are comparatively rich in nutrients when compared with those derived from plant materials and particularly those derived from wood. Nevertheless biochars in general are probably more imperative for use as a soil modifier and driver of nutrient transformation and less so as a primary source of nutrients (DeLuca *et al.*, 2009).

2.8 pH of biochar

Biochar used in soils improves alkalinity and it's capacity to increase the pH. Not all biochars are alkaline. The pH of biochar has been reported to vary from 4 to 12 depending on the pyrolysis conditions and feedstock used (Bagreev *et al.,* 2001). Additionally, it has been found that raising the pyrolysis temperature can increase the pH of some biochars. For instance raising the pyrolysis temperature from 310 to 850^o C, increased the pH of biochar produced from bagasse from 7.6 to 9.7 (Sohi *et al.,* 2010). Though high pH biochar can be produced, they might not have a big impact on the pH of soils when they are added and this effect is connected to biochar's acid neutralising capacity.

Biochar indirectly influence nutrient availability by changing soil pH. In view of the fact that biochar normally has higher pH than soil it acts as a liming agent generally increasing soil pH (Glaser *et al.,* 200l; Rondon *et al.,* 2007). Soil with higher pH increases nutrient availability and decreases the quantity of Al+3 and H+ ions residing in cation exchange sites, which can efficiently increases base saturation (Sohi *et al.,* 2010).

2.9 Application of biochar

Due to the variability of biochar types there are limited information available to farmers on how best to apply biochar and potential applications (Lehmann *et al.,* 2006). Conversely, with recent research and the potential widespread of biochar application, it is likely that the application strategy and specific machinery can be developed for its application.

There are numerous options for applying biochar. These include applying through liquid slurries and spreading by hand or machine and deep banding with manures or composts. Most of these have however not been researched. Field trials up to date have spread the incorporation of biochar into the soil through some type of tillage. This technique of application which reduces the movement of biochar though soil erosion can cause challenges for the application in pastures and no-tillage farming. Approximately biochar losses of 30% are connected with surface application of biochar and handling in commercial agricultural field (Blackwell *et al.*, 2009).

Strategies on timing and location of the application of biochar need to be established. According to Lehmann *et al.*, (2006) the highest amount of biochar that can be applied to soil has been evaluated by affirming that very high application rates of biochar (up to 140 ton C/ha), crop yield can achieve improvements with no recorded negative impacts. This high capacity of soil to accumulate pyrolysis-derived C combined with high stability of biochar results in long-term C sequestration.

2.10 Biochar for soil improvement

According to Hammond (2009) different types of biochar affect different types of soil in different climates in different ways, and the effects vary for different crops. Biochar can be generalized according to how they affect the soil chemical, physical, and biological properties.

Application of biochar for soil productivity may be a valuable tool to enhance infertile and degraded lands. The application of biochar to soil may improve nutrient supply to plants, as well as the physical and biological properties. Jessica and Peter (2011) stated that the irreversibility of the application of biochar needs researchers to conduct long-term studies to achieve a high level of certainty for healthy soil and productivity

2.11 Soil properties

Biochar addition to soil causes changes to soils ranging from chemical, physical and biological effects (soil biota).

2.11.1 Chemical

Remarkable improvements in soils chemical properties have been reported following biochar applications. These include:

1. Improved soil pH (Chan *et al*., 2007; Novak *et al*., 2009; Laird *et al*., 2010; Van Zwieten *et al*., 2010; Peng *et al*., 2011), thus reducing lime requirements.

2. Improved cation exchange capacity (CEC) (Chan *et al*., 2007; Laird *et al*., 2010; Novak et al., 2009; Van Zwieten *et al*., 2010; Peng *et al*., 2011).

3. Lowered N leaching thereby can possibly reduce fertiliser requirements (Chan *et al*., 2007; Van Zwieten *et al*., 2010).

4. Bioremediation through reduced mobility of heavy metals and organic soil contaminants such as insecticides (Hilber *et al*., 2009).

Biochar is normally of alkaline pH and may change soil pH in a favourable trend for most crops (Chan and Xu, 2009). The ash content of biochar is principally accountable for the modification of the soils pH.

Yeboah *et al.,* (2009) conducted a field trial in the semi-deciduous forest zone of Ghana with different rates of biochar used and after 6 weeks of plant growth and stated a decrease in soil pH. Oguntunde *et al.,* (2004), reported related statement in the forest savannah transition zone in Ghana.

High levels of CECs are due to high charge density per unit surface of organic matter which equates with a greater degree of oxidation, or high in surface charge area for cation adsorption and/ or amalgamation of both (Atkinson *et al*., 2010).

Steiner *et al*., (2008) established that biochar can operate as an absorber lowering N leaching and increasing N use efficiency. Nitrogen use efficiency is of great importance, especially to sustain future population growth.

2.11.2 Ion exchange capacity

High cation exchange capacity in soil has the capacity to bind cationic plant nutrients on the surface of biochar particles, humus and clay, thus nutrients are available for uptake by plants. High cation exchange capacity shows that the applied nutrients are held in soils relatively than leached during high rainfall. Soil with high cation exchange capacity translates to a high buffering capacity; meaning that when acidic or basic components are added have a smaller effect on soil pH (until a certain point) e.g. high-cation exchange capacity in soils takes a longer period to build up into an acidic soil in contrast with a lower-cation exchange capacity soil. On the contrary acidic soil with a high cation exchange capacity needs the application of additional lime to correct the pH of soil in contrast with acidic soil of lower cation exchange capacity.

Numerous of studies have demonstrated that biochar can augment the cation exchange capacity of the soil. When fresh biochar is exposed to water and oxygen in the soil environment, spontaneous reactions of oxidation occur, following an increase in the net negative charge and consequently increases cation exchange capacity (Joseph *et al.*, 2009). As such, biochar of particles which are matured or aged are related with high concentrations of negative charge, potentially upholding soil aggregation and increasing nutrient availability to plants (Liang *et al.*, 2006).

Conversely, Granatstein *et al.*, (2009) established that cation exchange capacity did not change drastically as a result of the application of biochar, even though there was a pattern of higher cation exchange capacity when biochar was added to soils with a low initial cation exchange capacity.

Inyang *et al.*, (2010) also considered the anion exchange capacity in bagasse biochars and recommended that the addition of biochar drastically improved the exchange capacities (cation and anion) of soils and enhanced nutrient holding capacities.

2.11.3 Nutrient transformation

Nitrogen is a very important in plant nutrient. The use of biochar to soils may support transformation of nitrogen and potentially enhancing its availability to plants. Soil biota is dependable on nitrogen mineralization and the biotic fixation of atmospheric nitrogen.

Nitrogen mineralization is the transformation of nitrogen seized in organic forms e.g. decaying plant, humus and animal matter) to forms accessible for uptake by plant roots e.g. ammonium and nitrate. Mineralizations are of two principal transformations catalyzed by different sets of biota. Firstly, ammonified organic nitrogen to ammonium and subsequently nitrified to nitrate.

It has been established that biochar increases nitrification rates in natural forest soils that have very low natural nitrification rates. Conversely soils in agricultural which previously have appreciable rates of nitrification, these effects of biochar on nitrification were therefore established to be minimal. Biochar additions to agricultural soils also decreased apparent ammonification rates (DeLuca *et al.,* 2009). Likewise Granatstein *et al.,* (2009) established that the addition of biochar to soils led to decreases in soil nitrate production (nitrification) and also decrease in the quantity of nitrogen available to plants.

DeLuca *et al.,* (2009) documents different experiments which indicated that biochar reduces nitrogen availability in tropical agricultural soils and increases nitrogen uptake by plants. Biochar is considered to bind ammonium ions from the soil solution, thus lowering their concentrations in the soil solution and also increases concentration in biochar particles. Immobilization of nitrogen on biochar ought to decrease nitrogen losses from soil through leaching.

Nitrogen is lost from the soil via volatilization of ammonia and denitrification which nitrate is transformed to nitrogen gas or the intermediates nitric oxide and nitrous oxide. Although biochar has the ability to reduce the potential for ammonia volatilization, it decreases the available of ammonium in the soil solution and slightly raises the pH of soils both situation do not favour ammonia formation and volatilization. Furthermore, biochar is considered to be capable of catalyzing the reduction of nitrous oxide to nitrogen gas, consequently ultimately denitrification and reducing the quantity of nitrous oxide (Van Zwieten *et al.,* 2009).

Rondon *et al.,* (2007) established that biochar additions drastically augmented biological nitrogen fixation by rhizobia at all application rates (30, 60 and 90 grams per kilogram). In addition they noted that the enhancement in biological nitrogen fixation and biomass productivity were appreciably greater compared with normal productivity achieved by conventional fertilizer application when biochar was not applied.

Rondon *et al.,* (2007) suggested that detailed field studies should be carried out to examine this significant enhancement in productivity. Nitrogen gas fixing bacteria are ubiquitous in soils; however no studies show biochar application having a direct effect on nitrogen assimilation by this set of nitrogen-fixing organisms.

Phosphorus is an extra vital plant nutrient. Microbial turnover and organic matter decomposition adjust phosphorus mineralization and thus its availability to plants.

Numerous studies have confirmed the enhancement of phosphorus uptake by plants in the existence of biochar, however little study has been documented on the fundamental mechanism for this enhanced uptake. Researchers recommend that biochar enhance the biological availability of sulphur a vital nutrient that depends on mineralization of organic forms of sulphur to cycle in soils (DeLuca *et al.,* 2009).

2.11.4 Physical

Biochar additions to soils that are infertile increases porosity, through the nature of its particle size and shape, and since biochar particularly have porous internal structure.

Besides, increased soil porosity they increase the surface area of soil (Jessica & Peter 2011).

The physical soil properties documented is as follow:

1. Enhance soil water permeability (Asai *et al*., 2009).

2. Enhance saturated hydraulic conductivity (SHC) (Asai *et al*., 2009).

3. Lowers soil strength (Chan *et al*., 2007, 2008; Busscher *et al*., 2010).

4. Change in soil bulk density (ρb) (Laird *et al*., 2010).

5. Alter aggregate stability (Busscher *et al*., 2010; Peng *et al*., 2011).

According to Laird *et al*., (2010) biochar amended soils preserve more water at gravity drained equilibrium (up to 15% for 20 g/kg treatment), had higher water retention at 1 and 5 bars soil water metric potential, (13% and 10% greater, respectively for 20 g/kg), and no effect was detected regarding saturated hydraulic conductivity. Soil columns were used and treatments consisted of 0, 5, 10, and 20 g-biochar/kg, with and without manure.

Related soil-water parameters were examined by Asai *et al*., (2009) and they concluded that applying biochar to upland rice paddies, enhanced soil water permeability and water holding capacity, thus the plant's water availability. They also established that biochar amendment improved the saturated hydraulic conductivity.

According Chan *et al*., (2008), stated that the field capacity of the biochar modified soil only increased with increased levels of biochar application however significant increases were detected only at the higher treatment levels of 50 t/ha and 100 t/ha of biochar.

Biochar augments the water retention of soils, consequently enhancing dry and or sandy soils and lowers irrigation requirements (Liang *et al.*, 2006). Through raising the water retention capacity of soil, one increases crops potential to retain more plant available water and thus increasing yields f crop and lowering water stress in critical periods of water restriction. As soils are saturated, the highest hydraulic conduction will be important for soil with the larger and further continuous pore system, whereas the contrary will be observed for soils with a further primary micro-pore system.

According to Kemper and Rosenau (1986), large pores in soils are normally related with fine tilt, sufficient aeration for the growth of plants and high infiltration rates.

The key mechanism following the increased water holding capacity and enhanced saturated hydraulic conductivity can be recognized by the adjustment of soil pore system.

Sandy soils with low water holding capacities, owing to a prevailing macro and meso pore systems present, with small to no organic material and clay at hand.

Consequently water molecules can only be seized by capillary forces and not by adsorption e.g. clayey soils (Hillel, 1980).

It is hypothesized that while modifying sandy soil with biochar the pore-system are modified and thus aids to increase the water content, through adsorbing more water molecules, when the biochar is highly porous and exhibits a variety of binding sites. Soils that are compacted and thus have a low infiltration potential, can be converted into waterlogged soils (Hillel, 1980) thus limiting root growth which leads to lower crop yields. In theory one can suppose that adjusted soils with pore-system consist of mainly micro-pores (silt or clay) and the hydraulic conductivity increases as biochar helps to shift the pore system to more macro or meso-pore sizes.

Busscher *et al*., (2010) accomplished that biochar demonstrates a trend to lower soil strength and did not state important results concerning soil aggregation.

According Guant and Cowie (2009) strong clay soils require more energy for field operations e.g. ploughing and biochar may lessen this through lowering soil strength. Bulk density is thus a key parameter to measure, as it is directly influenced by the soil structure (Hillel, 1980). This effect is due to the alteration in bulk density, before biochar amendment was more compacted and thus a higher bulk density available, and with biochar modification the soil strength decreased as the bulk density decreased. Biochar has a very low bulk density (0.30 – 0.43 g/cm^{-3}) (values adapted from Pastor-Villegas *et al.*, 2006) and particle density (1.47 $g \cdot cm^{-3}$; pine wood) (value adapted from Brown *et al.*, 2006); thus the volume it occupies in the soil and its low mass owing to its porous nature, soil strength will reduce with application. Broadly it is expected that the soil strength reduces as the content of biochar increases.

Significant factors which influence stabilisation and aggregate formation are:

• Soil fauna, specifically earthworms and termites;

• Microorganisms such as bacteria and fungi;

• Plant roots

• Inorganic binding agents e.g. oxides and calcium

• Environmental properties e.g. freeze-thaw cycles, dry-wet cycles.

According to Peng *et al*., (2011) no effect on aggregate stability was documented in their experimental design which had weak evidence due to their scientific method applied.

The study was concluded over an 11-day period, where 50 g of soil was incubated with 1% level of biochar application (by dry weight).

The sample size beside the short experimental period and devoid of plant test species is very impractical to test the effect of biochar on soil aggregation, which takes time in soils and is dependent on biotic factors.

According to Oades (1993), sand has structure as it has a pore-size distribution formed by the size and the packing of sand grains and that this structure can be changed by altering the packing of the sand grains by compaction or rearrangement by soil animals.

The structure is not modified drastically by drying and wetting cycles as the shrink and swell capacity is virtually zero (Oades, 1993), because of the absence or lack of clay- and organic matter content. Thus biological factors e.g. the root-microbial interaction in the rhizophere need to play a key role in structural development for sands.

Plants influence the rate, extent and the spatial development of the drying phase, modified by their root interactions and need for water. After aggregate formation, aggregate stabilization follows. Stabilization of aggregates of sand particles involves the growth of higher plants, fungi and bacteria in the pore system between grains (Oades, 1993). The sand grains are held together by:

(a) Colonies of organisms and their mucilage's (microbial aggregates)

(b) Roots and hyphae (root microbial aggregates)

(c) Metabolic products from the decomposition of fragments of higher plants (Forster, 1979, 1990)

Aggregate formation in sandy soil will aid to combat soil loss due to overland flow and wind erosion. The mechanisms that can stabilize aggregates of biochar is poorly understood and no studies has been conducted to identify the physical-chemical, and biological factors, which can possibly help in the formation and stabilisation of aggregation. The following are possible factors and mechanisms that can contribute to aggregate stabilization in sandy soils with biochar application (Hillel, 1980):

• Biochar can enhance root growth and thereby stimulate aggregation

• Improve microbial activity (e.g. rhizopheric bacteria and mycorrhizal fungi, which in direct association with roots form a more extensive rooting system through filaments know as mycelia and hyphae).

• Calcium carbonate, more so calcium (Ca).

Czimczik and Masiello (2007) suggested that Ca shows increase biochar stability, mainly by improving interactions with mineral surfaces.

2.11.5 Biological

The functioning of different biological communities within soils is a complex field of study. The following positive effects have been documented:

1. Improved biological N fixation (rhizobia) (Rondon *et al*., 2007).
2. Enhanced colonization of mycorrhizal fungi.
3. Earthworms showed preference for biochar amended soils (Van Zwieten *et al*., 2010).
4. Raising CH_4 uptake (Karhu *et al*., 2011).
5. Potential catalyst in lowering N_2O to N_2 (Van Zwieten *et al*., 2009).

Rondon *et al*., (2007) stated that evidence exists to show that increasing biochar amendments to soil can increase the proportion of N derived from fixation by *Phaseolus vulgaris* (common green bean) and this increased yields. When preparing acidic soils, the increased alkalinity effect of applied biochar, could help to increase rhizobia numbers, especially when they function optimum in neutral pHs.

According to Van Zwieten *et al*. (2010) earthworms show a very distinct preference for biochar amended ferrosol soils, when compared to the control.

Karhu *et al*., (2011) stated that increased CH_4 uptake was beneficial and available immediately after fresh biochar application to soil. The reason for the increased CH_4 uptake is unclear.

It has been recommended by Van Zwieten *et al*. (2009), that biochar enhances soil aeration, and thus decrease CH_4 production and increase CH_4 oxidation. There have been hypothesized that biochar may have the potential to catalyze the reduction of N_2O to N_2 (Sohi *et al*., 2009), however Van Zwieten *et al*., (2009) did not discover supporting proof to this arguments. This could be due to the fact that we are dealing with case specific scenarios and that each soil type will be affected differently according to the biochar (feedstock and pyrolysis needs to be defined) used and the amount applied under specific climatic conditions.

Soils can be observed as complex communities of organisms which are repeatedly shifting in response to soil characteristics and climatic and management factors, especially the addition of organic matter (Thies and Rillig 2009).

Conversely, addition of biochars to soils is probably to have different effects on soil biota (all organisms living within the soil) contrast to addition of fresh organic matter (biomass).

The differences arise because of the relative stability of biochar and the general lack of energy and biologically useable carbon in comparison with fresh organic matter.

Nevertheless, addition of biochar to soils affects the abundance, activity and diversity of soil biotic communities. Biochar addition to soils can stimulate microorganism activity in the soil, potentially affecting the soil microbiological properties (Hammes and Schmidt 2009).

Relatively supplying microorganisms with a prime source of nutrients, biochar is considered to improve chemical and physical environment in soils to provide microbes with a further favourable habitat (Krull *et al.*, 2010).

2.12 Effect of biochar application on crop production

The response of agricultural crops to various application levels and different biochars is vital for devising applicable strategies which are suitable for long term carbon sequestration in sustainable farming. According to Atkinson *et al*., (2010) the significance attached to the level at which biochar application may increase agricultural production is a key driver in any attempt to develop systems that economically incorporate pyrolysis products within the soil.

Asia *et al.,* (2009) studied the effects of biochar application on rice yields (*Oryza sativa* L.) and selected plant traits .The following were found: improved the response to N fertilizer treatments; biochar application lead to higher grain yields; improved xylem sap flow; reduced leaf chlorophyll concentration and concluded that biochar application is highly dependent on soil fertility and fertilizer management.

Singh *et al.,* (2010) proposed that timely availability of nitrogen can be ensured and maize productivity can be positively increased by combined use of mineral nitrogen and Organic manures.

However Khan *et al*., (2008) found that increase in plant height contributed to positive effect of N on vegetative growth.

Van Zwieten *et al*., (2010) found for wheat in the ferrosol soils, there was no significant difference in the absence of fertilizer, however with fertilizer, significant increases in biomass production were recorded, indicating a strong fertilizer by biochar interaction.

A pot trial was carried out by Chan *et al*., (2008) and they found in the absence of N fertilizer, biochar significantly increased total dry matter (TDM) of radish even at the lowest level of application (10 $t \cdot ha^{-1}$), and the yield increased with increased levels of biochar application to 50 $t \cdot ha^{-1}$.

Rondon *et al*., (2007) had contradicting data, were their pot trial experiments obtained the following results: bean yield increased by 46%; biomass production increased by 39% over the control at 60 $g \cdot kg^{-1}$ and 90 $g \cdot kg^{-1}$ biochar application; total N uptake decreased when biochar application were increased to 90 $g \cdot kg^{-1}$; and soil N uptake by N-fixing beans decreased by 14%, 17% and 50% when 30, 60, and 90 $g \cdot kg^{-1}$ biochar were added to soil. C/N ratios increased from 16 to 23.7, 28, and 35, respectively.

Oguntunde *et al.*, (2004) conducted an experiment on charcoal site and adjacent fields and found out that there were significant differences between the charcoal and the adjacent fields. Grain and biomass yield of maize increased by 91% and 44% respectively. Thus far studies have not shown any severe negative results from biochar amendments to agricultural soils.

2.13 Social and environmental issues

The global trend is gradually but certainly, moving towards sustainable production systems, waste minimization, reduced fossil fuel transport, alternative energy generating projects, conservation of native vegetation and mitigation of greenhouse gas emissions (Sims, 2002; Brownsort, 2009; Pandey 2009, Blaschek *et al*., 2010). When considering pyrolysis technology and biochar production, the following may arise, concerning the different pyrolysis methods employed in processing plants: is fast or slow pyrolysis systems more cost sufficient.

The difference in production costs and products generated may be vital to the economic feasibility of biochar (Pratt and Moran, 2010).

From an economic standpoint, producing biochar for agricultural amendment will only be profitable if the income generated is greater than fast pyrolysis (bio-oil) production systems. We do know that applying biochar to agricultural soils, produced dramatic yield improvements, reduced soil acidity (reduced lime requirements) and increased the water holding capacity (less irrigation needed). These are all agricultural benefits that will lead to greater economic income, but these results were proven by short term trials and for selected crop species. Primary motivations to produce biochar and applying commercially are as follow:

• Mitigating green house gases (especially CO_2);

• Selected soil chemical, physical and biological benefits;

• Increased agricultural crop yields;

• Economical growth (creating employment and contributing to the carbon-stock-market)

• Alternative 'cleaner' fuel option (substitute for fossil fuels; bio-oil- and gas production favoured).

Biochar is incompletely combusted (lack of oxygen during pyrolysis); therefore in the event of a fire, the applied biochar will complete the process of combustion and release extra carbon amounts in the atmosphere. This hypothetical scenario can be devastating especially since this will counter the exact event it was relieving. There is also evidence where charcoal was applied to undisturbed forest soils (carbon rich soils) in northern Sweden and studied over a 10 year period. As a result, there was mineralization (decomposition) of native soil organic matter with accelerated emissions of CO_2 (Wardle *et al.*, 2008). Again, applying biochar defeated the original purpose of mitigating greenhouse gases. Biochar application may be limited in the future to only degraded agricultural soils. Biochar use as an alternative mitigation technology needs to be evaluated and measured intensively according to effectiveness (relieving atmospheric CO_2), cost efficiency (compare to bio-oil production) and sustainability (long term agricultural effects).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location of the study area

The Study was conducted at the research field of Savannah Agriculture Research Institute (SARI) in Nyankpala. Nyankpala is located at the Tolon-Kumbugu District of the Northern Region of Ghana within the Guinea Savannah Agro-ecological Zone. Tolon – Kumbugu district has a population of 132,833 (Ghana Districts, 2012). SARI lies between latitude 9^o 25′ N and longitude 00^o 58′ W. The vegetation is an original wooded savannah. SARI is located 19km west of Tamale on the Tamale - Daboya road. The Institute covers an area of 2477.8 acres (1,002.7ha).

3.2 Climate of the study area

The mean annual rainfall is about 1043 mm. Rainfall peak with maximum of 156 mm and mean minimum of 67 mm. The mean daily maximum temperature ranges from 33 °C to 39 °C while mean daily minimum temperature ranges from 20°C to 22°C. The Daily range of relative humidity from April- October is ninety- six (96) percent in the night and seventy (70) percent in the afternoon. Daily sunshine ranges from 9.45 hours in November to 4.00 hours in the overcast months of August and September. Annual figures of evaporation from free water surface are approximately 1830 mm as against rainfall of about 1100 mm (SARI, 2004).

3.3 Soil of the study area

The rocks are voltaian sandstone formation. They are mainly shales and mudstone which have developed ferruginous layers. The ferruginous materials are hardened when exposed at the surface to form hard pans. The topography of the land is gently undulating and composed of three (3) low ridges or hills which have been separated into eastern, central and western uplands by two (2) broad and shallow depressions.

The Soils are generally gravelly and sandy. Top soils are thin above an underlying concretionary layer. The soil used for the study is Nyankpala series (Plinthic Acrisol) FAO-UNESCO (1988).

3.4 Survey of farm household

The study has two components a socio- economic and a field study.

3.4.1 Data collection method and sampling

Primary data was collected through a household survey, focus-group discussion, key informant interview, observations and questionnaire interviews. Information was collected at Nyankpala during the month of July to August 2012. Information was collected on the potential feedstocks available for the production of biochar, opportunity cost of the potential feedstock available.

Purposive sampling was used to identify 420 households in the community and simple random sampling was also used to sample 200 households using a questionnaire. The 200 households were chosen based on the sampling table guide for sample size decisions provided by Krejcie and Morgan (1970) to estimate the sample size.

3.5 Field experimentation

3.5.1 Site preparation

The site was cleared of all debris and weeds using cutlasses. The field was ploughed and harrowed in the first week of June in 2012. The layout of the field was also done during the first week of June in 2012. Maize was planted at a spacing of 80 cm by 40 cm resulting in a plant population of 62,500 plants/ha.

PLATE 3.1. Site Preparation of the study area at CSIR - SARI experimental site, Nyankpala

3.5.2 Field design

A 50 m x 50 m (0.25 ha) plot was demarcated in the field. Three main plots were demarcated which was 12.8 m x 12.8 m and in each main plot a four sub plots of 6.4 m x

6.4 m were demarcated and replicated three times in a Split plot experimental design. Main plots were pegged and separated from each other by two (2) m whiles the subplots were separated from each other by one (1) m. Three (3) treatments (0 t/h, 2 t/h and 4 t/ha) rice husk biochar were applied and four levels of inorganic nitrogen fertilizer (0, 30, 60 and 90kgN/ha) was also applied with each plot receiving a basal fertilizer application of 30 kg P/ha and 60 kg K/ ha to ensure adequate supply of these elements to the crop. In all, there were twelve (12) treatment combinations and three (3) replications.

PLATE 3.2. Field layout of the study area at CSIR - SARI experimental site, Nyankpala

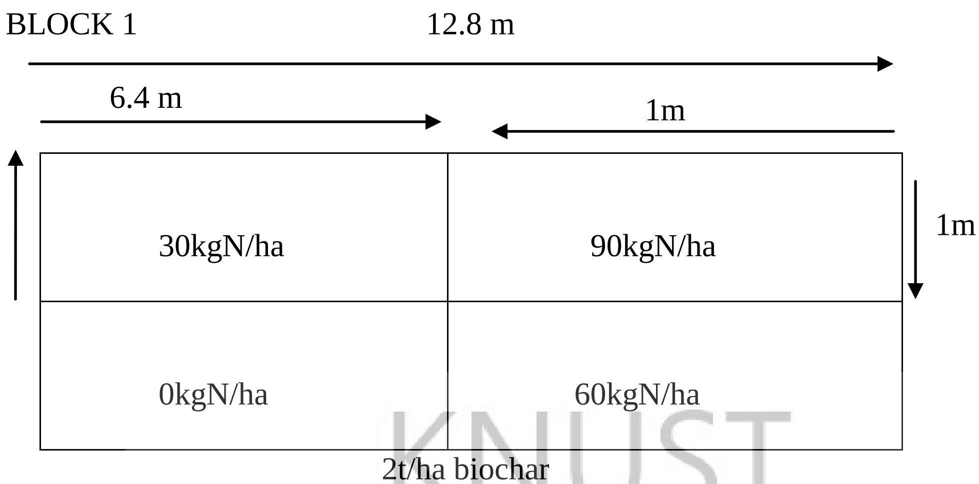


Figure 3.1 Schematic representation of the field design for one factor e.g. 2t/ha Biochar

TREATMENTS

T1: 0 t/ha rice husk biochar + 90 kg N

T2: 0 t/ha rice husk biochar + 60 kg N

T3: 0 t/ha rice husk biochar + 30 kg N

T4: 0 t/ha rice husk biochar + 0 kg N

T5: 2 t/ha rice husk biochar + 0kg N

T6: 2 t/ha rice husk biochar + 30 kg N

T7: 2 t/ha rice husk biochar + 90 kg N

T8: 2 t/ha rice husk biochar + 60 kg N

T9: 4 t/ha rice husk biochar + 0 kg N

T10: 4 t/ha rice husk biochar + 30 kg N

T11: 4 t/ha rice husk biochar + 60 kg N

T12: 4t/ha rice husk biochar +90kg N

3.5.3 Experimental plot layout

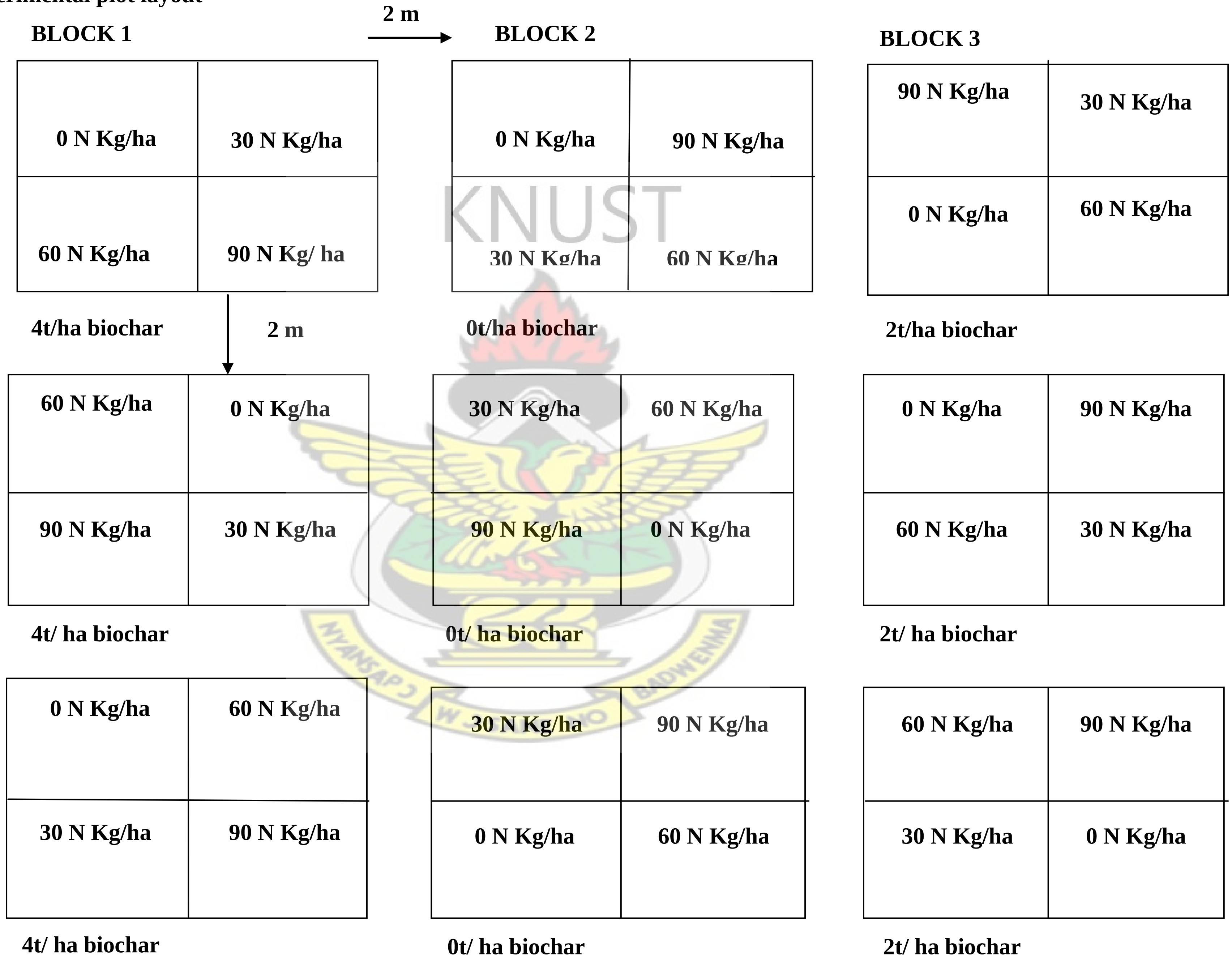


Figure 3.2 Schematic representations of randomized field design of field study at CSIR - SARI experimental field, Nyankpala

3.6. Biochar preparation

A slow pyrolyzer was used to prepare the rice husk biochar. The pyrolysis system consists of a batch reactor equipped with a programmable temperature controller (550^0C) and a cooling system to collect biochar. The batch reactor was filled with rice husk feedstock, covered with a fitting lid, and pyrolyzed under oxygen-limiting conditions. After pyrolysis, biochar in the reactor was allowed to cool overnight to room temperature. Biochar was collected from the reactor into sacks.

3.6.1 Biochar application

The biochar was surface applied and incorporated to the soil using hoe on the 14th of June, 2012.

PLATE 3.3. Biochar Application at the study area at CSIR - SARI experimental site, Nyankpala

3.7 Planting maize test crop

The maize variety (Dorke SR) planting stock was obtained from SARI-Nyanpkala. Planting was done on the 18th of June, 2012. The seeds were air – dried for three (3) days, sieved and cleaned of debris. Germination test was conducted before planting. The germination percentage was 95. Four (4) seeds were planted per hole. Refilling was done one week after planting. Maize seedlings were thinned to two (2) plants per hole which resulted in the plant population of 62,500 plants/ha.

PLATE 3.4. Planting of maize test crop at the study area at CSIR - SARI experimental site, Nyankpala

PLATE 3.5. Thinning of maize test crop 2 WAP at CSIR - SARI experimental site, Nyankpala

3.8 Field management

Weeding was done twice within the cropping season; the first three weeks after planting and the second at 7 WAP. Phosphorus (P) and potassium (K) were broadcast and incorporated before planting. The P source was triple superphosphate and the K source was muriate of potash. Nitrogen in the form of urea was split applied. One-third at the first application of fertilizer was done one (1) WAP and two- thirds applied six (6) WAP.

PLATE 3.6. First weeding at the study area at CSIR - SARI experimental site, Nyankpala

PLATE 3.7. First fertilizer application of one-third inorganic N at 1 WAP at CSIR - SARI experimental site, Nyankpala

3.9 Data collection

3.9.1 Growth measurements

The growth data collected were height, number of leaf, girth and number of ears. This was done at two (2) weeks interval starting at 2 WAP and terminating 10 WAP. Five (5) maize plants were selected at random from each plot and tagged for growth measurements. Plant height was measured using a tape measure from the ground level to the apical portion of the stem and plant girth was measured by venier callipers. The numbers of leaves were visually counted.

3.9.2 Harvesting of maize test crop

Harvesting was done 12 WAP. The entire plant population on the plot was harvested except the two (2) border rows by cutting maize plants at the ground level and weighed to represent the total fresh weight. A sub-sample of five (5) plants was randomly selected cut and weighed. The selected plants were then separated into ears (cob + grains) and total stover (stem, leaves and husks). The plant parts i.e. ears and total shoot were weighed and their weights recorded as fresh weights. The ears were further separated into cobs and grains by shelling. The various plant parts were put in brown paper envelopes and then oven dried to 60˚C for 48 hours to estimate their dry matter yield. Each sample was milled to pass through a 20 mm mesh sieve. The weight of ears, cobs, biomass and grain yield were determined after harvest. Grain and Stover yields were estimated per hectare at grain moisture content of 15 %.

Grain and stover yields were determined as:

A = area per 1 ha (10,000m^2)

B = area in 6.4 m x 6.4 m (40.96 m^2)

C = yield in 6.4 m x 3.2 m (20.48 m^2)

D = yield per 1 ha (10,000m^2)

$$D = \frac{C \times A}{B}$$

3.9.3 Weighing of samples

Samples of maize were weighed using the CAMRY Weighing Scale (ANASCO SCALES). An empty sack was weighed to determine initial weight. The total weight of the sample and the sack was also taken. The weight of the maize sample was derived by subtracting the initial weight from the total weight.

A = weight of maize sample

B = initial weight of sack

C = total weight of sack and sample

A = C – B.

3.10. Soil Sampling

Initial soil samples were collected from the thirty-six (36) plots at a depth of 0-15cm and 15cm-30cm with soil auger totaling seventy-two (72) samples. Samples of seventy-two (72) were also collected after harvest with a soil auger. Five samples were collected and sub-sampled at each soil depth and conveyed in 2 mm poly bags to the laboratory for testing. The soil samples were sent to Soil Research Institute laboratory, Kwadaso, Kumasi for chemical analysis.

3.10.1 Soil analysis

Soil samples were air-dried for 24 hours after and which they were ground and sieved using a 2 mm mesh sieve. Chemical analysis was carried out to determine % total N, available P (Bray No.1), exchangeable K, pH, CEC, base saturation and soil organic carbon.

3.10.2 Soil pH determination

Twenty grams of soil were mixed with 50 ml distilled water and stirred at intervals for 30 minutes. The pH of the suspension was then measured with a pH meter.

3.10.3 Soil nitrogen (N)

Percent total N was determined by micro – kjeldahl digestion method. One gram (1g) each of the soil samples was digested in conc. H_2SO_4 using selenium catalyst. The compound formed was then titrated with 0.02 NHCl.

3.10.4 Cation exchange capacity (CEC)

Cation exchange capacity (CEC) was determined by the sum of the exchangeable bases (K, Mg, Ca, Na) and exchangeable Al and H expressed in cmolc/kg.

3.10.5 Soil organic carbon

Soil organic carbon content was determined using the dichromate-acid oxidation method. 0.5 g of soil in an Erlenmeyer flask was added 10ml concentrated sulphuric acid, 10 ml 0.1667*M* $K_2Cr_2O_7$ and 10 ml of concentrated orthophosphoric acid. After the addition of water, the solution was allowed to stand for 30 minutes and back titrated with 1.0*M* $FeSO_4$ solutions with diphenylamine indicator.

The organic carbon content was calculated from the following equation:

$\% C = M \times 0.39 \times 10^{-3} \times (a-b) / S$

Where

M = Molarity of $FeSO_4$

a = Volume of $FeSO_4$ solution required for blank titration

b = Volume of $FeSO_4$ solution required for sample titration

S = Weight of oven – dried sample in grams

0.39 = 3 x 0.001 x100% x 1.3 (3 = equivalent weight of carbon)

1.3 = Compensation factor allowing for incomplete combustion.

3.10.6 Bulk density

Soil bulk density at 0 – 15 cm depth was determined by the core method described by Blake and Hartge (1986). A cylindrical metal sampler 5 cm in diameter and 15 cm long was used to sample undisturbed soil. The core was driven to the desired depth (0-15 cm) and the soil was carefully removed to preserve the known soil volume in situ. The soil was weighed, dried at 105 ^{o}C for two (2) days and reweighed. Bulk density was computed as:

$Pb = M_S / V_t$

Where

Pb = Soil bulk density (gcm^{-3})

M_S = Mass of the oven dry soil (g)

V_t = Total volume of soil (cm^3)

3.11. Plant and rice husk biochar analysis

3.11.1. Plant and rice husk biochar sampling

Maize grain, maize cob, maize husk and the rice husk biochar were kept in paper envelopes and oven-dried at 60 ^{o}C for 48 hours after which they were milled to pass through 2 mm mesh sieve.

3.11.2. Nitrogen

Total nitrogen were determined by the Kjeldahl method in which plant material and rice husk biochar was digested with concentrated sulphuric acid and hydrogen peroxide with selenium as catalyst. The organic N present was converted into NH_4^+. The ammonium ion, which reacted with the excess of sulphuric acid to form ammonium sulphate, was distilled off in an alkaline medium into boric acid.

The $H_2BO_3^-$ that was formed was titrated with standard hydrochloric acid back to H_3BO_3. About 20.0 g oven-dried plant materials and rice husk biochar was ground in a stainless steel hammer mill with a sieve mesh of 1 mm, and mixed well to ensure homogeneity. Approximately 0.2 g of the plant material and rice husk biochar each was weighed into a Kjeldahl flask, a tablet of selenium catalyst was added and 5 ml of concentrated H_2SO_4 was also added to the mixture. This was digested on the Electrothermal Kjeldahl apparatus for three hours. After the clear digest has cooled, about 20 ml of distilled water was poured into the Kjeldahl flask containing the digested material before it was transferred into a 100 ml distillation tube. In the distillation tube another 20 ml distilled water was added plus 20 ml 40 % NaOH then distilled for 4 minutes. The distillate was received in a conical flask containing 20 ml of 4 % boric acid with PT5 indicator (methyl red and bromocresol green indicators). The received greenish solution was titrated against 0.1 M HCl dispensed from a burette. % N was calculated from the volume of HCl used to attain end-point.

Calculation:

$$\% \text{ N DM}^{-1} = \frac{(c - d) \times M \times 1.4 \times mcf}{S}$$

Where

c = volume of 0.1 M HCl used for sample titration.

d= volume of 0.1 M HCl used for blank titration.

M= molarity of HCl

1.4 = 14x0.001x100 %(14= atomic weight of N)

s= weight of sample (gram)

3.11.3. Organic carbon

Organic carbon content of organic material was determined using the dichromate-acid oxidation method. To 0.5 g of organic material in an Erlenmeyer flask was added 10ml concentrated sulphuric acid, 10 ml 0.1667*M* $K_2Cr_2O_7$ and 10 ml of concentrated orthophosphoric acid. After the addition of water, the solution was allowed to stand for 30 minutes and back titrated with 1.0*M* $FeSO_4$ solution with diphenylamine indicator.

The organic carbon content was calculated from the following equation:

$$\% C = \frac{M \times 0.39\times10^{-3} \times (c-d)}{s}$$

where

M = Molarity of $FeSO_4$

c = volume of $FeSO_4$ solution required for blank titration

d = volume of $FeSO_4$ solution required for sample titration

s= weight of oven –dried sample (gram)

1.3= compensation factor for incomplete combustion

0.39 = 3x 0.001 x100% x 1.3 (3 = equivalent weight of carbon)

3.11.4. Determination of phosphorus and potassium in plant material

Total Phosphorus and potassium were determined in plant ash using the Vanado-Molybdenum method. Approximately 0.5 g of the plant material was weighed into a porcelain crucible and ashed in a muffle oven at a temperature of 450 – 500 ^{o}C. The ashed sample was removed from the oven after cooling then made wet with 1–2 drops of distilled water and 10 ml of 1:2 dilute HNO_3 added. The crucible was then heated on a water bath until the first sign of boiling was observed. The crucible was removed and allowed to cool. The content was filtered into a 100 ml volumetric flask using a no. 540 filter paper. The crucible was washed two times with about 5 ml distilled water followed by the filter which was also washed two times with about 20 ml distilled water. After 10 ml each of ammonium vanadate and ammonium molybdate solutions were added and shaken thoroughly. The solution was allowed to stand for 10 minutes for full colour development and then filled to the 100 ml mark. A standard curve was also developed concurrently with P concentrations ranging from 0, 1, 2, 5, 10, and 15 to 20 μg P per millilitre of solution. The absorbance of the sample and standard solutions were read on the 54 spectrophotometer (spectronic 21D) at a wavelength of 470 nm. A standard curve was obtained by plotting the absorbance values of the standard solutions against their concentrations. Phosphorus concentration of the samples was determined from the standard curve. Potassium in the ash solution was determined using a Gallenkamp flame analyzer. Potassium standard solutions were prepared with the following concentration: 0, 10, 20, 40, 60 and 100 μg K per milliliter of solution. The emission values were read on the flame analyzer. A standard curve was obtained by plotting emission values against their respective concentrations.

3.12 Soil moisture content determination

A 12 cm rod Hydrosense display unit was used to determine the soil moisture content. To measure the soil moisture content the 12 cm rod Hyrosense display unit is fully inserted into the soil and with a press of READ it displays the measurement result as percent volumetric water content. Three (3) readings were obtained at each sub plot and their averages determined from the plot. The period of the probe output is measured in milliseconds. The Hydrosense operating system applies standard calibrations to convert the probe response to volumetric water content. Readings were taken every other day.

3.13 Nutrient uptake

Nutrient uptake was determined for maize grain, cob and husk. This was calculated from the nutrient concentrations obtained from the tissue analysis and oven-dry matter weight expressed in kg/ha.

3.14 Percent N recovery

Fertilizer N utilization or recovery by the crop is the fraction of the fertilizer N taken up by the plant in relation to the rate of fertilizer N applied and was finally calculated as:

% N recovery = (Yield NF- Yield N0F / Napp) *100

Where

NF = Yield N uptake in the fertilized treatment

N0F = Yield N uptake in the control treatment

Napp = the amount of N applied in kg/ha (Yeboah *et al.*, 2009).

3.15. Data analysis

Data was analyzed using GenSTAT 2008 software. Results are presented in tables and graphs and least significant difference were used as mean separate.

CHAPTER FOUR

4.0 RESULTS

4.1. Survey of farm households

4.1. Production of agriculture crops in Nyankpala in 2011 and 2012

Table 4.1 shows major agriculture crops produced in Nyankpala in the year of 2011 and 2012. Ground nut is the dominant crop cultivated in the area with production amounting 18,920 metric tons in 2011 and 22,200 metric tons in 2012. The quantities of rice produced in the area were 6,600 and 8,200 metric tons in 2011 and 2012. Quantities (in metric tonnes) of millet, cowpea, ground nut and guinea corn produced are given in (Table 4.1).

Table 4.1. Production of agricultural crops in Nyankpala for 2011 and 2012

	Production in metric tonnes	
Crop	**2011**	**2012**
Maize	6,600	8,200
Rice	4,180	7,500
Millet	696	528
Guinea corn	875	714
Ground nut	18,920	22,200
Cowpea	2000	1,900

Source: MOFA, 2012

4.1.2 Potential feedstock available in the Nyankpala community

The information collected from the survey at Nyanpkala during the months of July and August from 200 sampled farmers indicates that the potential feedstocks available are maize stover, maize cobs, groundnut shell, rice husk, rice straw, shea nut shell, guinea corn stover and cowpea shell (Table 4.2).

4.2. Opportunity cost of potential biochar feedstock

Table 4.2 shows the potential feedstocks available in Nyankpala, current major uses and the opportunity cost for biochar production. The survey revealed that 28.5 % of the respondent leave maize stover on the farm while 25% use it as source of fuel for domestic cooking, 7.5% of the farmers use it for compost, 10% of the farmers are interested in feeding it to their animals, 10% of the farmers burn the maize stover and 19% will rather use the maize stover for the preparation of biochar.

The survey also revealed that 15% of the sampled population leave maize cob on the farm while 36% use it as source of fuel for cooking. Maize cobs are not used for compost and animal feed by the farmers, only 5% of the farmers use it for burning, 44% of the farmers are interested in using it for the preparation of biochar. Respondents indicated that more 40% of the ground nut shell, rice husk, rice straw, shea nut shell, millet stover, guinea corn stover and cowpea shell could be used for biochar preparation (Table 4.2).

Table 4.2. Potential biochar feedstock and current uses in Nyankpala

Major current use	Maize stover	Maize cob	Ground nut shell	Rice husk	Rice straw	Shea nut shell	Millet stover	Guinea corn stover	Cow pea shell
	←				(%)				→
Left on farm	28.5	15	10	40	13	11.5	10	22.5	15
Fuel	25	36	40	5	7.5	52.5	23	14	25
Compost	7.5	0	2	0	6	0	3.5	2.5	0
Animal feed	10	0	35	0	15	0	12.5	1.5	0
Burnt	10	5	7.5	10	12	28	7.5	11.5	12.5
Biochar	19	44	5.5	45	46.5	8	43.5	48	47.5

4.3 Initial soil analysis

The initial soil pH was slightly acidic, 6.22 at 0-15 cm depth and 6.21 at 15-30 cm depth (Table 4.3). Initial soil organic carbon content was low (0.62 and 0.52%) at 0-15 cm and 15-30 cm respectively. Initial nitrogen content was low (0.06 and 0.05%) at 0-15 cm and 15-30 cm depth respectively. Initial phosphorus content at the study site was 4.92 at 0-15 cm and 5.55mgkg^{-1} at the depth of 15-30 cm. Initial potassium was 0.16 Cmolkg^{-1} at 0-15 cm depth and 0.17 Cmolkg^{-1} at 15-30 cm depth. Effective cation exchange capacity (ECEC) was 2.89 and 3.00 Cmol/kg at 0-15 cm and 15-30 cm respectively before the experiment at the study site. The texture of the soil at the study site was sandy loam at 0-15 and 15- 30 cm depth. Base saturation, percentage sand, silt and clay at 0-15 and 15-30 cm depth before the experiment at the study site have values presented in Table 4.3 below.

Table 4.3. Some initial chemical and physical properties of soil

Soil parameters	**0 – 15 cm**	**15 – 30 cm**
pH(1:1 H_2O)	6.22	6.21
Org C (%)	0.62	0.52
% N	0.06	0.05
P (mg/kg)	4.92	5.55
Ca (Cmol/kg)	1.85	1.88
Mg (Cmol/kg)	0.75	0.8
K (Cmol/kg)	0.16	0.17
Exchangeable acidity (Cmol/kg)	0.11	0.1
ECEC (Cmol/kg)	2.89	3.00
% Base saturation	97.00	97.00
Sand (%)	62.85	61.48
Silt (%)	33.82	35.18
Clay (%)	3.33	3.34
Texture class	Sandy loam	Sandy loam

4.4 Soil analysis at maize harvest

Interactions between biochar and inorganic N application significantly influenced soil organic carbon (SOC) content at both 0-15 and 15-30 cm depth (Tables 4.4 and 4.5). At 0-15 cm depth SOC was least in control plots (0.65%) and highest at 4 ton biochar + 90 kg N/ha. Similar trend was observed at 15-30 cm depth (Table 4.5).

Soil total N at 0-15 and 15-30 cm depth was similarly influenced by the interaction between biochar and inorganic N. The least soil total N was observed in control plots where no biochar or inorganic N was applied and was highest at highest biochar and inorganic fertilizer N application rates.

Soil pH at 0-15 cm depth ranged between 6.22 and 6.48 while at 15-30 cm depth, it ranged from 6.23 to 6.49 (Tables 4.4 and 4.5). Interaction of biochar and inorganic fertilizer N applied significantly influenced soil pH at both depths. At harvest, effective cation exchange capacity (ECEC) at both soil depths was significantly influenced by the interaction of biochar and inorganic N fertilizer (Table 4.4 and 4.5). However, exchangeable acidity was not influenced significantly by the interaction of biochar and inorganic N fertilizer application.

Table 4.4. Effect of biochar and inorganic N fertilizer application on some chemical properties of soil at 0-15cm depth

Treatment	**Organic C** (%)	**N** (%)	**pH(1:1H_2O)**	**ECEC** (Cmol/kg)	**Ex. Acidity** (Cmol/kg)
0t/ha biochar+ 0kgN	0.65	0.06	6.22	2.89	0.12
0t/ha biochar+ 30kgN	0.66	0.08	6.24	2.95	0.12
0t/ha biochar+ 60kgN	0.67	0.09	6.26	3.04	0.15
0t/ha biochar+ 90kgN	0.68	0.10	6.27	3.07	0.10
2t/ha biochar+ 0kgN	0.76	0.15	6.31	3.17	0.10
2t/ha biochar+ 30kgN	0.86	0.18	6.34	3.29	0.10
2t/ha biochar+ 60kgN	0.89	0.19	6.37	3.31	0.10
2t/ha biochar+ 90kgN	0.98	0.22	6.39	3.48	0.10
4t/ha biochar+ 0kgN	1.15	0.34	6.42	3.6	0.10
4t/ha biochar+ 30kgN	1.26	0.35	6.44	3.69	0.10
4t/ha biochar+ 60kgN	1.54	0.36	6.47	3.75	0.10
4t/ha biochar+ 90kgN	1.64	0.37	6.48	3.82	0.10
LSD ($P < 0.05$)	0.10	0.01	0.14	0.13	ns*
CV%	0.65	0.06	2.2	10.4	8.6

* ns not significant

Table 4.5. Effect of biochar and inorganic N fertilizer application on some chemical properties of soil at 15-30cm depth

Treatment	Organic C (%)	N (%)	pH(1:1H_2O)	ECEC (Cmol/kg)	Ex. Acidity (Cmol/kg)
0t/ha biochar+ 0kgN	0.66	0.06	6.23	3.05	0.1
0t/ha biochar+ 30kgN	0.68	0.08	6.25	3.07	0.12
0t/ha biochar+ 60kgN	0.69	0.09	6.26	3.13	0.10
0t/ha biochar+ 90kgN	0.70	0.10	6.27	3.15	0.12
2t/ha biochar+ 0kgN	0.73	0.14	6.35	3.23	0.10
2t/ha biochar+ 30kgN	0.87	0.18	6.37	3.43	0.10
2t/ha biochar+ 60kgN	0.89	0.19	6.38	3.54	0.10
2t/ha biochar+ 90kgN	0.98	0.24	6.39	3.69	0.10
4t/ha biochar+ 0kgN	1.15	0.34	6.45	3.78	0.10
4t/ha biochar+ 30kgN	1.27	0.35	6.46	3.81	0.10
4t/ha biochar+ 60kgN	1.55	0.35	6.47	3.88	0.10
4t/ha biochar+ 90kgN	1.69	0.37	6.49	3.95	0.10
LSD ($P < 0.05$)	0.10	0.01	0.14	0.13	ns*
CV%	10.9	14.2	2.2	10.4	8.6

* ns not significant

4.5 Chemical analysis of rice husk biochar

The pH of rice husk biochar was slightly acidic, organic carbon was high and total nitrogen content was high (Table 4.6) compared to soil of the site. Values of exchangeable potassium, available phosphorus, exchangeable calcium, magnesium, sodium, extractable aluminium, extractable iron and ash are presented in Table 4.6.

Table 4.6. Some chemical properties of rice husk biochar used for the experimentation

pH (w/v) in H_2O	Org C	N	Ash	P	Ca	Mg	K	Na	Al	Fe
	←	(%)	→	←			(mg/kg)			→
6.51	33.3	0.67	52.13	0.63	2.32	0.89	0.54	0.23	3.69	1.20

4.6 Rainfall and temperature of the experimental site at Nyankpala

The total monthly rainfall (mm) and temperature (^{o}C) of the experimental site is presented (Figs 4.1 and 4.2).

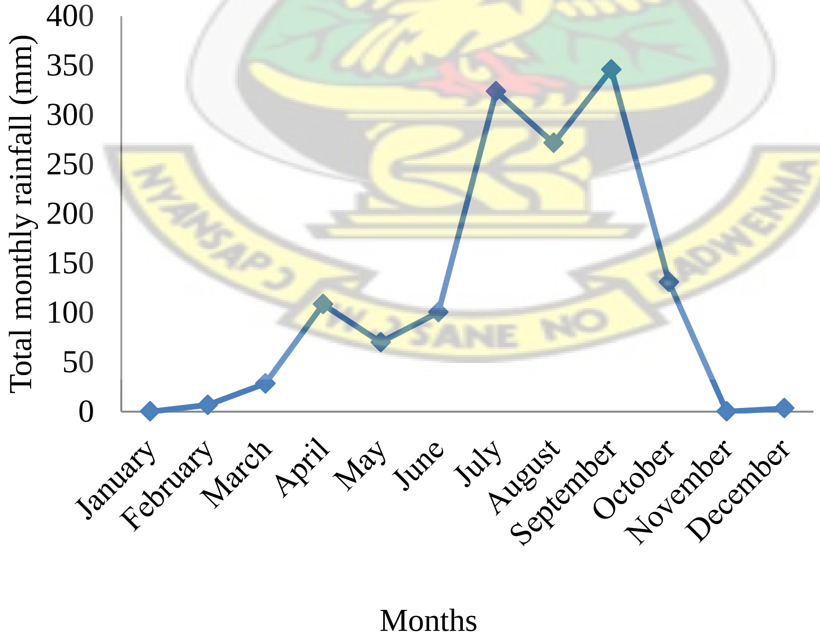


Figure 4.1.Total monthly rainfall (mm) at the experimental site at Nyankpala

Source: SARI Metrological station (2012)

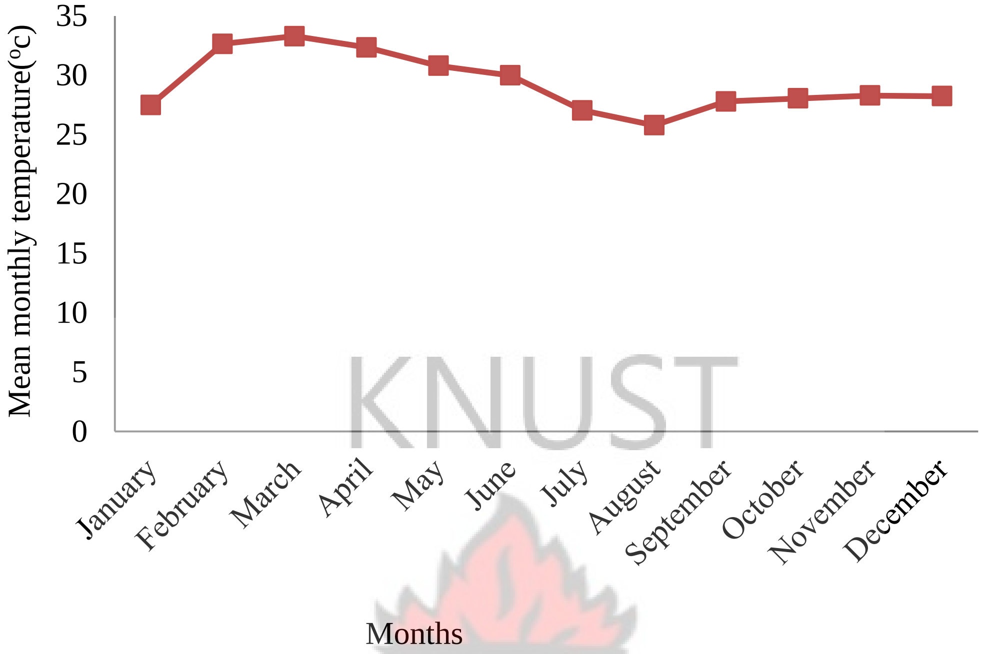


Figure 4.2. Mean monthly temperature (°c) at the experimental site at Nyankpala

Source: SARI Metrological station (2012)

4.7 Soil moisture content

Interaction between biochar and inorganic fertilizer N resulted in significant difference in soil moisture content (SMC). The volumetric soil moisture content varied between 18 and 27% during the experiment. Soil moisture content increased with increased rate of biochar application at 4 WAP. At 5 WAP, SMC generally increased at 4t/ha biochar with 4t/ha biochar + 90kgN recording the highest SMC (Fig.4.4).

Soil moisture content (SMC) increased in the order control < 2t/ha biochar < 4t/ha biochar along increasing rate of inorganic nitrogen application. Furthermore, 4t/ha biochar + 90kgN has significantly higher SMC than lower rates of biochar treatments with same inorganic nitrogen at 4 and 5 WAP. However the trend changed at 6 and 7 WAP where 4t/ha biochar + 30kgN recorded the highest SMC (Fig.4.3) and (Fig.4.4). At 8 WAP 4t/ha biochar + 60kgN recorded the highest soil moisture content (Fig.4.5).

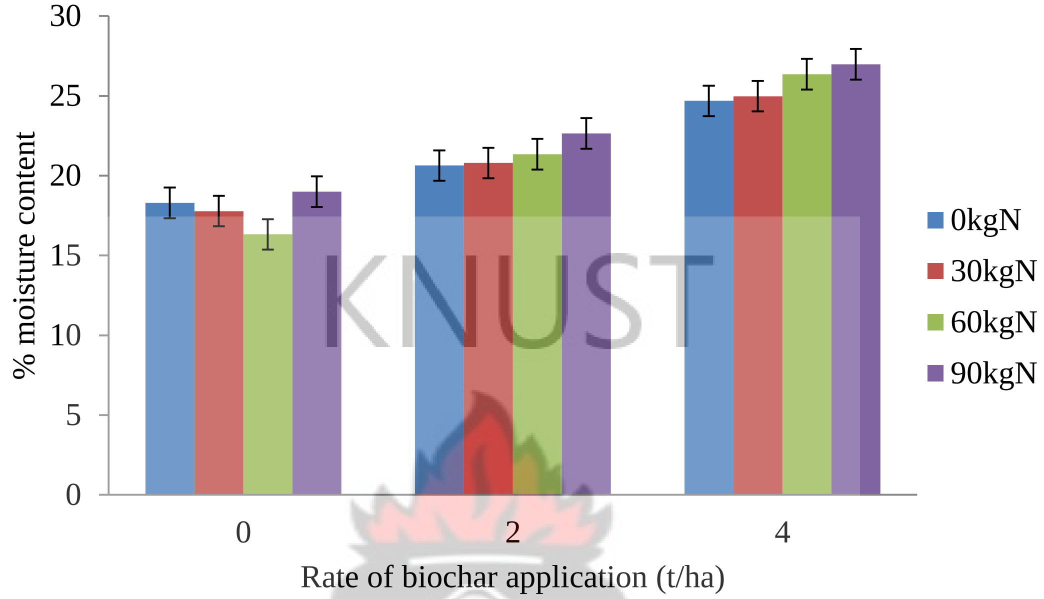


Figure 4.3. Soil moisture content as influenced by the interaction of biochar and inorganic N application at 4 WAP. Bars are LSD

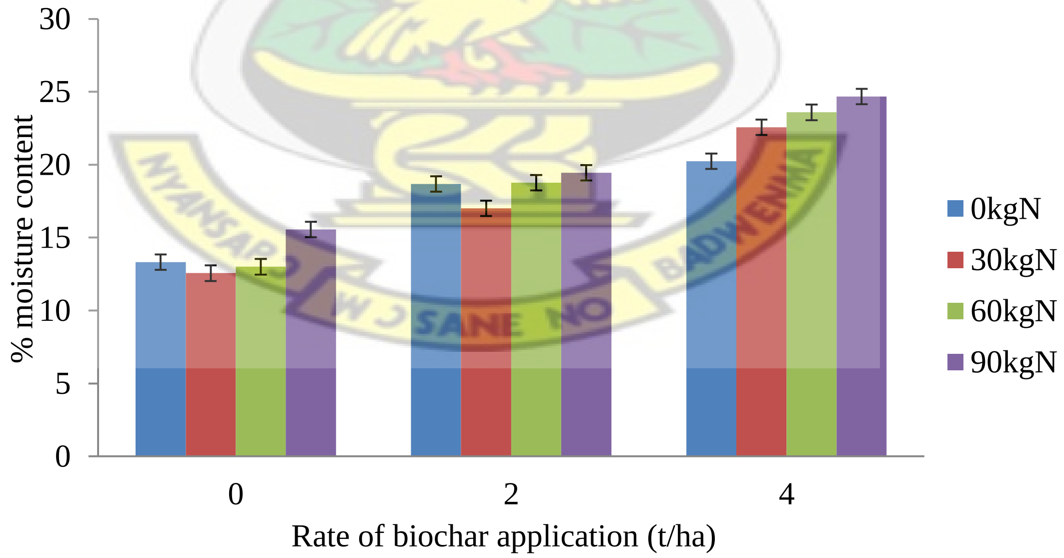


Figure 4.4. Soil moisture content as influenced by the interaction of biochar and inorganic N application at 5 WAP. Bars are LSD

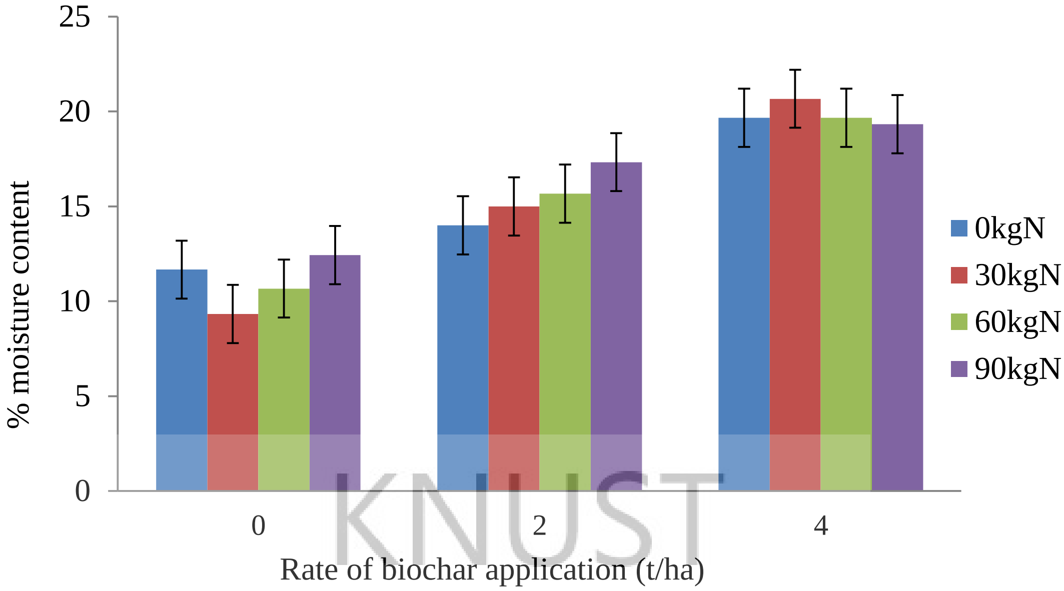


Figure 4.5. Soil moisture content as influenced by the interaction of biochar and inorganic N application at 6 WAP. Bars are LSD

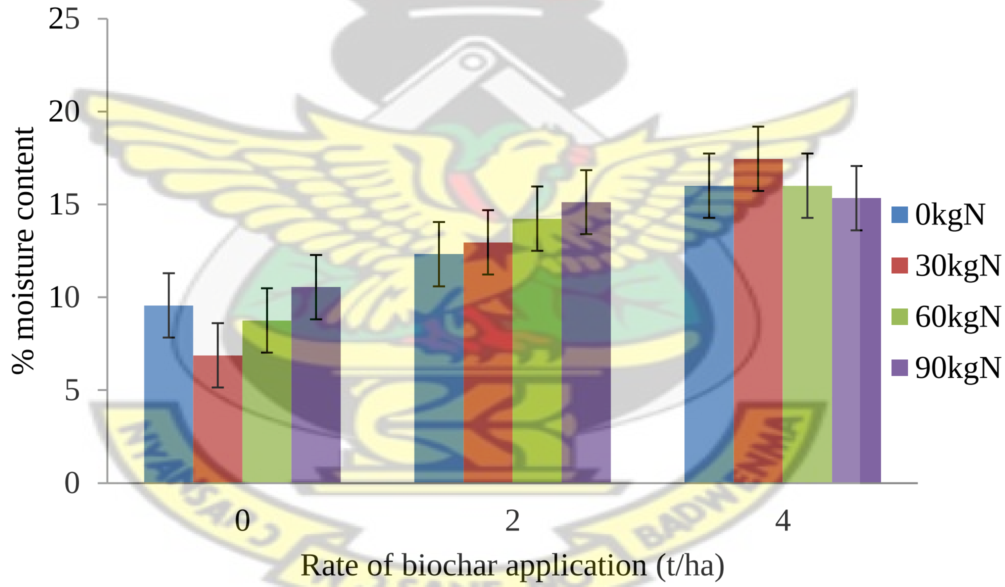


Figure 4.6. Soil moisture content as influenced by the interaction of biochar and inorganic N application at 7 WAP. Bars are LSD

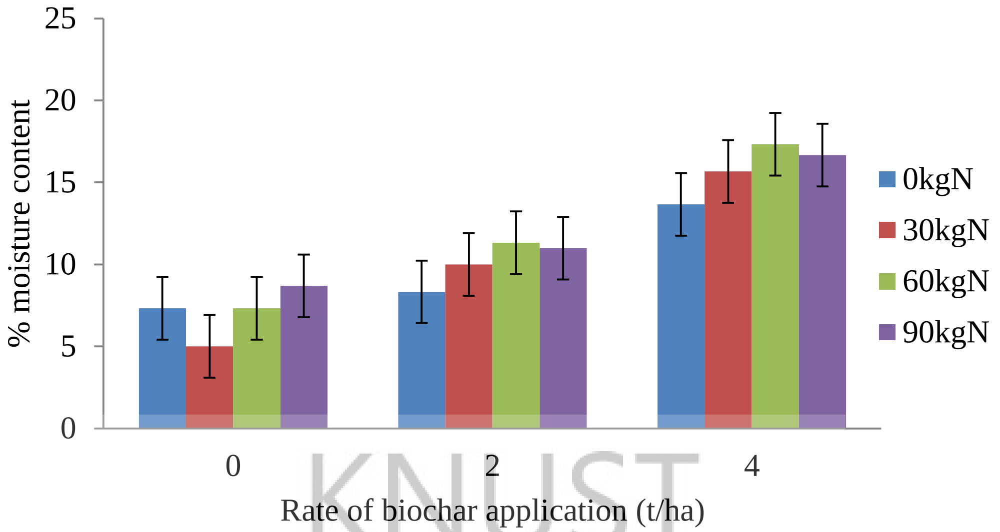


Figure 4.7. Soil moisture content as influenced by the interaction of biochar and inorganic N application at 8 WAP. Bars are LSD

4.8 The effect of rice husk biochar and inorganic N on the growth parameters of maize

Maize height increased with time peaking at 8 WAP (Appendix A). At 50% flower stage there were significant differences in maize height due to the treatments (Table 4.7). The rate of growth was rapid during the vegetative phase of the maize up to 8th week after which growth slowed down as the reproductive phase was initiated. The number of leaves per plant generally increased with time peaking at the 8th week (Appendix B). At the 50% flower stage, both biochar and inorganic N did not influence the number of leaves per plant, which ranged from 10 to 11 (Table 4.7). There were significant differences in plant girth at 50% flower stage.

Table 4.7. Effects of rice husk biochar and inorganic nitrogen fertilizer on maize growth at 50% flower stage

Treatment	Plant Height (cm)	Plant Girth (cm)	Number of Leaves
0t/ha biochar+0kgN	109.43	4.43	10
0t/ha biochar+30kgN	123.38	4.52	10
0t/ha biochar+60kgN	131.51	4.55	10
0t/ha biochar+90kgN	139.57	4.59	10
2t/ha biochar+0kgN	114.99	4.49	10
2t/ha biochar+30kgN	125.93	4.56	10
2t/ha biochar+60kgN	133.67	4.56	10
2t/ha biochar+90kgN	141.60	4.56	10
4t/ha biochar+0kgN	137.30	4.58	10
4t/ha biochar+30kgN	139.04	4.59	11
4t/ha biochar+60kgN	138.93	4.61	11
4t/ha biochar+90kgN	144.00	4.70	11
LSD(P< 0.05)	0.17	0.07	ns*
CV%	0.90	0.60	1.20

*ns not significant

4.8. The effect of rice husk biochar and inorganic nitrogen on maize grain yield

The results showed that grain yield was influenced significantly ($P < 0.05$) by the application of biochar and inorganic nitrogen (Fig. 4.8). The combined treatments produced yields which were significantly higher than sole biochar and inorganic nitrogen application. The combined treatment of 4t/ha biochar + 90kg N recorded the highest grain yield of 2.84 t/ha and the control recorded the lowest grain yield of 0.8 t/ha. At each biochar rate, increased N rate resulted in significant increased grain yield.

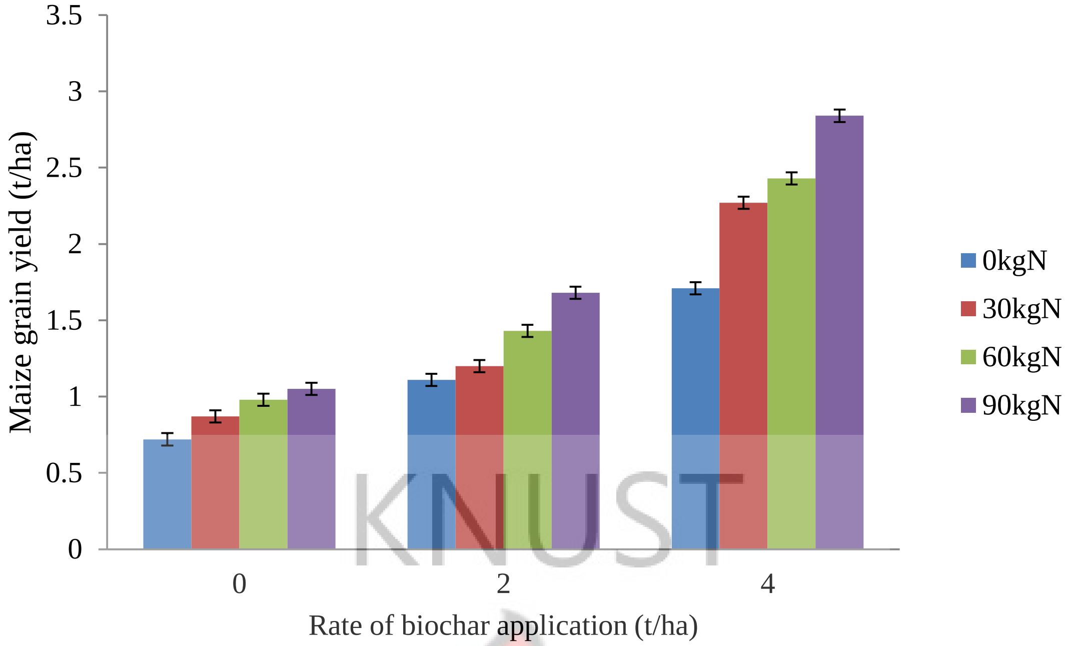


Figure 4.8. Effect of biochar and N fertilizer interaction on maize grain yield. Bars are LSD

4.9. Nitrogen concentrations of maize grains, cob and husk

Nitrogen concentration in the maize grain was significantly influenced by combined biochar and inorganic N application. The combined treatments contained higher nitrogen content than the sole biochar and inorganic N treatments. Similar trend was observed in the cob and husk but the differences observed were not significant. Nitrogen content of the maize grain ranged from 1.35 to 1.75 % for all treatment. The nitrogen content of the maize cob ranged from 0.33 to 0.98 %. The highest and lowest N content was obtained by 2t/ha biochar + 60kgN/ha and 2t/ha biochar + 30kgN/ha, respectively. The nitrogen content of the maize husk ranged from 0.26 to 0.70 with the highest and lowest N obtained at 4t/ha biochar + 90kgN/ha and at control.

Table 4.8 Nitrogen concentrations of maize grains, cob and husk

	Nitrogen Concentration (%)		
Treatment	Grain	Cob	Husk
0t/ha biochar+0kgN	1.49	0.65	0.70
0t/ha biochar+30kgN	1.47	0.68	0.54
0t/ha biochar+60kgN	1.49	0.35	0.49
0t/ha biochar+90kgN	1.66	0.82	0.47
2t/ha biochar+0kgN	1.38	0.47	0.47
2t/ha biochar+30kgN	1.75	0.33	0.37
2t/ha biochar+60kgN	1.73	0.98	0.37
2t/ha biochar+90kgN	1.63	0.54	0.42
4t/ha biochar+0kgN	1.49	0.44	0.37
4t/ha biochar+30kgN	1.40	0.36	0.35
4t/ha biochar+60kgN	1.35	0.51	0.26
4t/ha biochar+90kgN	1.38	0.60	0.40
LSD (P<0.05)	0.12	ns*	ns*
CV%	7.2	13.56	11.65

*ns not significant

4.9.1 Nitrogen uptake by maize grain, cob and husk

Nitrogen uptake in the grain and cob was significantly influenced by the interaction of biochar and inorganic N fertilizer but not in the husk (Table 4.9). Nitrogen uptake ranged from 10.73 to 39.20 kg N/ha, in the maize grain and 12.20 to 32.34 kg N/ha, in the cob. At each biochar level, increased N application resulted in increased N uptake in both the grain and the cob.

Table 4.9. Nitrogen uptake of maize grain, cob and husk

	Nitrogen Uptake(kg/ha)		
Treatment	**Grain**	**Cob**	**Husk**
0t/ha biochar+0kgN	10.73	12.20	1.25
0t/ha biochar+30kgN	13.00	13.12	1.30
0t/ha biochar+60kgN	14.41	13.50	1.30
0t/ha biochar+90kgN	17.43	18.86	1.26
2t/ha biochar+0kgN	15.32	13.63	1.23
2t/ha biochar+30kgN	21.00	15.10	1.39
2t/ha biochar+60kgN	24.74	17.34	1.25
2t/ha biochar+90kgN	27.40	19.60	1.36
4t/ha biochar+0kgN	25.48	16.85	1.30
4t/ha biochar+30kgN	31.78	18.12	1.33
4t/ha biochar+60kgN	32.81	22.75	1.37
4t/ha biochar+90kgN	39.20	29.40	1.56
LSD (P<0.05)	0.07	0.24	ns*
CV%	13.40	15.78	12.21

*ns not significant

4.10 Fertilizer N recovery

Table 4.10 shows the nitrogen recovery in the maize grain, cob and husk. Interaction of biochar and inorganic N resulted in a marked difference in N recovery of the grain and cob but was marginal in the husk. Nitrogen recovery ranged from 7.57 to 21% in the grains, 1.44 to 13.94% in the cob and 0.1 to 1% in the husk.

Addition of biochar resulted in marked increased N recovery, however increasing inorganic N fertilizer did not result in consistent N recovery (Table 4.10)

Table 4.10. Percentage N recovery of maize grain, cob and husk

Treatment	Grain	Cob	Husk	Total
0t/ha biochar+0kgN	-	-	-	-
0t/ha biochar+30kgN	7.57	3.07	0.26	10.9
0t/ha biochar+60kgN	6.13	2.17	0.26	8.57
0t/ha biochar+90kgN	7.44	1.44	1.0	9.88
2t/ha biochar+0kgN	-	-	-	-
2t/ha biochar+30kgN	18.93	4.90	0.23	24.03
2t/ha biochar+60kgN	15.70	6.18	0.53	22.41
2t/ha biochar+90kgN	13.42	6.63	0.14	20.19
4t/ha biochar+0kgN	-	-	-	-
4t/ha biochar+30kgN	21.00	4.23	0.10	25.33
4t/ha biochar+60kgN	12.22	9.83	0.12	22.17
4t/ha biochar+90kgN	15.24	13.94	0.29	29.47

CHAPTER FIVE

5.0 DISCUSSION

5.1 Potential feedstock availability and opportunity cost for biochar production in Nyankpala

The survey conducted showed that rice husk/straw, cowpea shell, millet stover, guinea corn stover and shea nut shell could be potential feedstock for biochar production. Traditionally, most of the agricultural residues generated in the Nyankpala area are scarcely utilized and no cost is tagged to these residues. The opportunity cost for biochar production is thus low owing to the very little cost value. In practice, not all the agricultural residues can be assembled and exploited for either biochar production or bioenergy due to ecosystem functions, technical limitation and/ or other uses (Moses *et al.*, 2011). The survey showed that rice husk and rice stover had greater potential for the production of biochar due to the fact that these residues have less alternative uses. Maize generates more residue than any of the crops cultivated in Nyankpala e.g. maize stover and maize cob and has greater potential for biochar production (Table 4.1). However there is high demand for other uses including animal feed and source of fuel for the household and fencing. These uses can influence its availability for biochar production. Although groundnut is the dominant crop produced at Nyankpala, the current uses of the residue such as source of fuel for the home and feed for livestock will limit its availability for biochar production. Sheanut shell, millet stover, guinea corn stover and cowpea shell are all potential feedstock for the production of biochar. However the current uses such as fuel for domestic use, animal feed and composting in the locality is high and thus would affect its use for the production of biochar.

These potential feedstocks need to be evaluated with regards to their chemical constituents before recommending them for application. In addition their interactions with inorganic fertilizers would have to be assessed with different soil types and climatic condition. According to McHenry (2009) the suitability of a particular residue as a potential feedstock for biochar production relies on various characteristics such as ash, moisture and nitrogen content.

5.2 Initial and final soil chemical and physical properties

Generally, biochar application to the soil altered the soil nutrient status. Biochar application increased soil organic C, total N, ECEC and pH. In the short term, it was found that increases in soil nutrients were primarily associated with the nutrient content of the applied biochar. The biochar used in this study contained more organic C and Ash (Table 4.6). Accordingly, it was observed that there were significant increases due to increase rates of biochar application to the soil. The nutrient content in biochar depends on the source of the feedstock and pyrolysis condition (Kookana *et al.*, 2011). Bagreev *et al.*, (2001), reported that ash content increases from 61.7% to 76% when heat temperature of sewage sludge was raised from 400°c to 800°c. There were significant increase in soil pH, organic C, total N and ECEC among the treatment combinations; this is not surprising given that the biochar used is predominantly rich in organic C (33.3%) and ash content (52.1%).

Application of biochar can add chemically active surfaces that modify the dynamics of soil nutrients or facilitate soil reaction, modify soil bulk density, increase porosity, improve water holding capacity (Asai *et al.*, 2009; Laird *et al.*, 2010), and the enhancement of biological N fixation (Rondon *et al.*, 2007). Effective cation exchange capacity (ECEC) increased significantly in all treatment combinations only when biochar with inorganic N fertilizers was mixed in the soil. This result corroborate with previous studies, which generally find a rapid ECEC response with fully-incorporated biochar amendments (Novak *et al.*, 2009). There might be greater cation retention over time due to increased ECEC with biochar aging, and biochar movement into the mineral soil. Biochar that are produced freshly has less ability to retain cations resulting in less CEC (Chan *et al.*, 2008; Lehmann *et al.*, 2008) but as they age and incorporation in the soil, the surfaces of biochar particles oxidize and interact with soil constituents, resulting in an increase in functional groups and greater surface negative charge (Liang *et al.*, 2006), which leads to increases in CEC.

With an increase in CEC, we would expect greater cation retention. The direct and indirect enhancements suggest biochar could be effective at altering and potentially improving soil nutrient status.

Biochar can indirectly affect nutrient availability by altering soil pH. Since biochar typically has higher pH than soil it can act as a liming agent resulting in an overall increase in soil pH (Glaser et al., 200l; Rondon et al., 2007). Higher soil pH increases nutrient availability and decreases the proportion of Al^{+3} and H^{+} ions occupying cation exchange sites, which effectively increases base saturation (Sohi *et al.*, 2010). The starting pH of the tested soil was 6.22 whereas biochar had a pH of 6.51. The higher pH of the biochar likely explains the increase in the soil pH when biochar was applied.

Report from the study showed that biochar played an essential role in nutrient cycling thus affecting N retention when applied to soils. The study showed that, the effects of biochar on soil N was largely positive, where N increased significantly at harvesting. Increases in N may have resulted from the ability of biochar to lower N leaching

(Chan *et al.,* 2007; Van Zwieten *et al.,* 2010). This also corroborates with Steiner et al., (2008) who reported that biochar operates as an absorber lowering N leaching and increasing N use efficiency. Biochar application to soil has generally resulted in positive effects on soil fertility (Lehmann *et al.,* 2006), particularly in sandy and infertile soils. However increasing evidence for negative consequences, particularly related to effects on soil N, stresses the importance of achieving a better understanding of potential site implications once biochar is irreversibly added to the soil.

Nitrogen losses associated with leaching from the soil profile are of large concern in most savannah soils, because they are typically N deficient and are infertile. Biochar has been found to decrease nitrogen leaching when added to agricultural soil (Lehmann *et al.,* 2008), which can improve fertilizer use efficiency and reduce leaching.

Biochar application strategies could have a considerable impact on soil processes and affect the fate of biochar particles in soil. Application of biochar to savannah soils may be limited to broadcast and incorporation in order to prevent loss of biochar through either wind or water erosion. Blackwell *et al.,* (2009) estimated biochar losses of 30% associated with handling and surface application of biochar to a commercial agricultural field.

5.3 The effect of rice husk biochar and inorganic nitrogen fertilizer on growth parameters of maize

The variation of maize plant height was caused by different rates of N. This increase in plant height could be attributed to positive effect of N on vigorous vegetative growth (Khan *et al*., 2008). The results (Table 4.7) further showed that the rice husk biochar and inorganic N fertilizer application had values relatively higher at 2t/ha and 4t/ha than the 0t/ha biochar applications. Singh *et al.,* (2010) suggested that timely availability of nitrogen could be insured and corn productivity can be positively increased by combined use of mineral nitrogen and Organic manures.

The rate of growth was rapid during the vegetative phase of the maize plant up to 8 WAP, growth slowed down as the reproductive phase was initiated. This might be due to the remobilization of carbohydrates in the cob.

5.4 The effect of rice husk biochar and inorganic nitrogen fertilizer on maize grain yield

Maize grain yield is the ultimate product of various yield components. Biochar and inorganic nitrogen caused significant variation in grain yield (Fig 4.8). The possible explanation for increase in grain yield with biochar in the combined treatment of biochar and inorganic N include the effect of biochar on soil physio-chemical properties such as enhanced water holding capacity, increased cation exchange capacity (CEC), and providing a medium for adsorption of plant nutrients and improved conditions for soil micro-organisms (Chan *et al*., 2007; Asai *et al*., 2009; Six *et al*., 2004). Biochar efficiently adsorbs ammonia (NH_3) (DeLuca *et al.*, 2009) and acts as a binder for ammonia in soil, therefore have the potential to decrease ammonia volatilization from soil surfaces. These results are in accordance with Singh *et al.*, (2010) who suggested that timely availability of N could be ensured and corn productivity can be positively increased by combined use of mineral N and organic manures.

This result is in line with Oguntunde *et al.*, (2004) who found that grain yield of maize increased by 91% at the charcoal sites and also conforms with Rondon *et al*.,

(2007) who conducted a pot trial experiment and found that bean yield increased by 46% over the control compared with 60 g/kg and 90 g/kg biochar application.

5.5 Nitrogen concentrations of maize grains, cob and husk

The combined treatment of biochar and inorganic N fertilizer resulted in higher nutrient content values than the sole inorganic N applied. A comparable trend was observed for the cob and the husk. Marschner (1995) stated that mineral nutrient and sink source relationship indicates that as much as 80% of the total N is located in the grain of matured cereals.

5.6 Plant nitrogen uptake by maize grain, cob and husk

The application of biochar increased N uptake significantly in the grain and cob but not the husk. According to Rowell (1993) N usually is required in the largest amount in crops. It is likely that N were lost via leaching or through runoff due to the moist condition prevailing at that time. This might have resulted in low uptake values in all the treatment combinations. Conversely this study is in contrary to the experiment conducted by Major *et al.*, (2010) who demonstrated that the application of biochar significantly increased maize N uptake for 20 t biochar/ha treatment, but not for the 8 t biochar/ha treatment.

This observation might be due to the information that the combined treatments enhanced the soil which was efficiently exploited by the maize plants as compared to the sole organic or inorganic treatment. Conversely this observation corroborates the findings of DeLuca *et al.*, (2009) who documented that the application of biochar increases N uptake by plants. Plant N uptake is increased through the amendment of biochar which has the ability to improve N fertilizer use efficiency.

5.7 Percent N recovery of maize grain, cob and husk

The amount of N derived from the grain were higher than the cob and husk in the treatment combination when biochar was applied with inorganic N fertilizer than sole inorganic N fertilizer reflecting differences in N yields.

The % N concentration in plant (grain, cob and husk) derived from biochar treatment were low in all treatments suggesting that some amount of N was added for plant uptake however the amount of % N recovery derived from the biochar treatments was low, less than 30% which lead to low recovery in all the treatments.

One reason that could have resulted to the low N recovery might have been due to the moisture condition prevailing at the time which could have worsened this situation. Conversely this observation is in line with Yeboah *et al.*, (2009) who reported that the application of biochar resulted in low N recovery. Additionally, the recovered N was primly deposited into the grain as reported by Bigeriego *et al.*, (1979).

5.8 Effects of biochar application on soil moisture

The volumetric soil moisture content varied between 18% to 27% during the experiment. The trend of soil moisture content increased with the rate of biochar application at 4 WAP.

The main mechanism behind the increased water holding capacity and improved saturated hydraulic conductivity can be attributed to the modification of the soil's pore system (Hillel, 1980). Sandy soils have low water holding capacities, due to a dominant macro-and meso-pore systems present, with little to no organic material and/ or clay at hand (Hillel; 1980, Oades; 1993). Asai *et al.*, (2009) conducted a field studies and found that applying biochar to upland rice paddies, improved soil water permeability and water holding capacity. They also found that biochar amendment improved the saturated hydraulic conductivity.

Since biochar has high amount of micro and meso pores in which strong capillary forces are effective, large amounts of water can be stored by biochar. This could be the reason for soil water content being high in 4t/ha biochar at 4 to 5 WAP. However the trend changed from 7 to 8 WAP where the 4t/ha biochar treatment had high values of moisture content (Fig 4.6 and 4.7). This might be due to the reason that high rainfall was recorded at that time and this affected all the treatments, however 4 t/ha biochar treatments obtained higher values respectively.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The survey conducted in Nyankpala in the northern part of Ghana indicates that the following maize stover, maize cob, groundnut shell, rice husk, rice straw, sheanut shell, millet stover, guinea corn stover and cowpea shell biomass are available. The potential feedstocks for biochar use were highest for cowpea shell (47.5 %), guinea corn stover (48 %), rice straw (46.5 %) and rice husk (45 %). The result of this study demonstrates that the application of biochar and inorganic nitrogen fertilizer increased maize grain yield than sole application of inorganic N fertilizer. Biochar application improved chemical properties such as pH, % N, organic C and ECEC. Combined application of the biochar and inorganic N fertilizer in the rate of 90 kg N plus 4t/ha biochar results in yields higher than the sole application of each nutrient source.

6.2 Recommendation

- The combined application of 4t/ha Biochar + 90kgN/ha and 2t/ha Biochar + 90kgN/ha is thus recommended for smallholder farmers.
- Long term studies of the treatments used in this study should be carried out to further ascertain their effects on the physico-chemical properties of the soil.

REFERENCES

Amonette, J.E. and Joseph, S. (2009). Characteristics of biochar: microchemical properties. Chapter 3. In: Lehmann, J. and Joseph, S. (Eds.), Biochar for Environmental Management – Science and Technology, Earthscan, London: 33 – 52.

Asai, H., Samson, B.K., Stephan, H.M., Songyikhangsuthor, K., Homma, K., Kiyono, Y., Inoue, Y., Shiraiwa, T. and Horie, T. (2009). Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield. Field Crop Research, 111: 81 – 84.

Atkinson, C.J., Fitzgerald, J.D. and Hipps, N.A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. Plant and Soil, 337: 1– 18.

Badiane, O. and Delgado, C. L. (1995). A 2020 vision for food, agriculture and the environment, Discussion Paper 4. International Food Policy Research Institute, Washington, DC.

Bagreev, A., Bandosz, T.J. and Locke, D.C. (2001). 'Pore structure and surface chemistry of adsorbents obtained by pyrolysis of sewage sludge-derived fertilizer', Carbon 39: 1971–79.

Bigeriego, M., R.D. Hauck, and R.A. Olson. (1979). Uptake, trans-location and utilization of N–depleted fertilizer in irrigated corn. Soil Sci. Soc. Am. J. 43:528-533.

Blackwell, P., Riethmuller, G. and Collins, M. (2009). ‘Biochar application to soil’, in Lehmann, J and Joseph, S, Biochar for environmental management: science and technology, Earthscan, United Kingdom: 207–26.

Blake, G. R. and Hartge, K. H. (1986). Bulk density. In A. Klute (ed). Methods of soil Analysis. Part 1. Physical and Mineralogical Methods. Agronomy Monograph No. 9. 101 Amer. Soc. Agronomy and Soil Science Soc. Amer.

Blaschek, H.P., Ezeji, T.C. and Scheffran, J. (2010). Biofuels from agricultural wastes and by products. 1st ed. Wiley-Blackwell, Iowa, USA.

Boateng, A.A. (2007). ‘Characterization and thermal conversion of charcoal derived from fluidized-bed fast pyrolysis oil production of switchgrass’, Industrial Engineering and Chemical Research 46: 8857–62.

Brown, R.A., Kercher, A.K., Nguyen, T.H., Nagle, D.C. and Ball, W.P. (2006). Production and characterization of synthetic wood chars for use as surrogates for natural sorbents. Organic Geochemistry, 37: 321 – 333.

Brownsort, P. (2009). Biomass pyrolysis processes: performance parameters and their influence of biochar system benefits. MSc thesis, University of Edinburgh.

Busscher, W.J., Novak, J.M., Evans, D.E., Watts, D.W., Niandou, M.A.S. and Ahmedna, M. (2010). Influence of pecan biochar on physical properties of a Norfolk loamy sand. Soil Science, 175: 10 – 14.

Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A. and Joseph, S. (2008). Using poultry litter biochars as soil amendments. Australian Journal of Soil Research, 46:437 – 444.

Chan, K.Y. and Xu, Z. (2009). 'Biochar: nutrient properties and their enhancement', in Lehmann, J. & Joseph, S. Biochar for environmental management: science and technology, Earthscan, United Kingdom: 67–84.

Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A. and Joseph, S. (2007). 'Agronomic values of Green waste biochar as a soil amendment', Australian Journal of Soil Research 45: 629–34.

Cleaver, K.M. and Schreiber, G.A. (1994). Reserving the spiral; the population, agriculture and environment nexus in sub-Saharan Africa. World Bank, Washington, DC.

Czimczik, C.I. and Masiello, C.A. (2007). Controls on black carbon storage in soils. Global Biogeochemical Cycles, 21, GB3005, doi: 10.1029/2006GB002798.

Day, D., Evans, R.J., Lee, J.W. and Reicosky, D. (2005). 'Economical CO2, SOx and NOx capture from fossil-fuel utilization with combined renewable hydrogen production and large-scale carbon sequestration', Energy 30(14): 2558- 79.

DeLuca, T.H., MacKenzie, M.D. and Gundale, M.J. (2009). 'Biochar effects on soil nutrient transformations', in Lehmann, J. and Joseph, S. Biochar for environmental management: science and technology, Earthscan, United Kingdom: 251–70.

Downie, A., Crosky, A. and Munroe, P. (2009). 'Physical properties of biochar', in Lehmann, J & Joseph, S, Biochar for environmental management: science and technology, Earthscan, United Kingdom: 13–32.

Dovanan, G. and Casey, F. (1998). Soil fertility management in sub-Sahara Africa In: World Bank technical paper no. 480

Eswaran, H., Almaraz, R., van den Berg, E. and Reich, P. (1997). An assessment of the soil resources of Africa in relation to productivity. Geoderma 77:1–18.

FAOSTAT (2005). Food and Agriculture Organization of the United Nations Statistical Databases. (Available from http://faostat.fao.org/default.aspx; last accessed 1st June, 2012).

FAO-UNESCO (1988). Soil map of the world. Revised legend.

Forster, S.M. (1979). Microbial aggregation of sand in an embryo dune system.Soil Biology and Biochemistry, 11: 537-543.

Forster, S.M. (1990). The role of microorganisms in aggregate formation and soil stabilization. Types of aggregation. Arid Soil Research and Management, 4: 85-98.

Ghana districts (2012). Addressing agriculture production in northern region (online) Available from: http// www.ghanadistrict.comcontent (accessed on 17th March, 2012).

Gladwin, C. H., Buhr, K. L., Goldman, A., Hiebsch, C., Hildebrand, P. E., Kidder, G., Langham, M., Lee, D., Nkedi-Kizza P. and Williams, D., (1997). Gender and soil fertility in Africa. In: R. J., Buresh, P.A., Sanchez & F., Calhoun (eds.). Replenishing soil fertility in Africa. ASA-SSSA Special Publication 51: 219. American Society of Agronomy.

Glaser, B., L., Haumaier, G., Guggenberger and W., Zech (2001). The Terra Preta phenomenon: A model for sustainable agriculture in the humid tropics. Naturwissenschaften 88:37–41.

Granatstein, D., Kruger, C.E., Collins, H., Galinato, S., Garcia-Perez and M., Yoder, J. (2009). Use of biochar from the pyrolysis of waste organic material as a soil amendment: final project report, Centre for Sustaining Agriculture and Natural Resources, Washington State University.

Guant, J. and Cowie, A. (2009). Biochar, greenhouse gas accounting and emissions trading.Chapter 18. In: Lehmann, J. and Joseph, S. (Eds.), Biochar for Environmental Management – Science and Technology, Earthscan, London: 317 – 340.

Hammes, K. and Schmidt, W.I. (2009). Changes of biochar in soil, in Lehmann, J and Joseph, S., Biochar for environmental management: science and technology, Earthscan, United Kingdom: 169–82.

Hammond, J.A.R. (2009). The best use of biomass? Greenhouse gas life cycle analysis of predicted pyrolysis systems. MSc thesis, University of Edinburgh.

Hillel, D. (1980). Fundamentals of soil physics. Academic Press Inc., New York.

Hilber, I., Wyss, G.S., Mäder, P., Bucheli, T.D., Meier, I., Vogt, L., and Schulin, R. (2009). Influence of activated charcoal amendment to contaminated soil on dieldrin and nutrient uptake by cucumbers. Environment Pollution, 157: 2224 – 2230.

Inyang, M., Gao, B., Pullammanappallil, P., Ding, W.C., and Zimmerman, A.R. (2010). Biochar from anaerobically digested sugarcane bagasse, Bioresource Technology 101(22): 8868–72.

Jessica, S. and Peter, S. (2011). Biochar: Implications for aagriculture productivity. Technical Report 11.06. Department of agriculture, fisheries and forestry. ABERE

Jones, D.L., Edward-Jones, G. and Murphy, D.V. (2011). Biochar mediated alterations in herbicide Break down and leaching in soil, Soil biology and Biochemistry 43: 804–13.

Joseph, S., Peacocke, C., Lehmann, J. and Munroe, P. (2009). 'Developing a biochar classification and test methods', in Lehmann, J and Joseph, S, Biochar for environmental management: science and technology, Earthscan, United Kingdom: 107–26.

Kapkiyai, J., Woomer, P. L., Qureshi, J., Smithson, P. C. and Karanja, N. (1997). Effects of fertilizer and organic inputs on soil organic matter and nutrient dynamics in a Kenyan Nitisol. Paper presented at the International symposium on carbon and nutrient dynamics in natural and agricultural ecosystem, Harare, Zimbabwe, April 1996. TSBF, Nairobi, Kenya.

Kemper, W.D. and Rosenau, R.C. (1986). Aggregate stability and size distribution. In: Klute, A., (ed.). Methods of Soil Analysis. ASA and SSSA, Madison, Wisconsin: 425 – 442.

Keiluweit, M., Nico, P.S., Johnson, M.G. and Kleber, M. (2010). Dynamic Molecular Structure of Plant Biomass-Derived Black Carbon (Biochar), Environmental Science & Technology 44(4): 1247–53.

Khan, H.Z., M.A., Malik and M.F., Saleem (2008). Effect of rate and source of organic material on the production potential of spring maize (Zea mays L.). Pak. J. Agric. Sci. 45(1):40-43

Kookana, R.S., Sarmah, A.K., Van Zwieten, L., Krull, E. and Singh, B. (2011). Biochar application to soil: agronomic and environmental benefits and unintended consequences, Advances in Agronomy 112: 103–43.

Krejcie, R.V. and Morgan, D.W. (1970). Determining sample size for research activities. Educational and psychological measurement. 30. p. 607- 610

Krull, E. (2009). 'Stabilisation of organic carbon in soil through biochar production' in an analysis of greenhouse gas mitigation and carbon sequestration opportunities from rural land use, CSIRO National Research Flagships: Sustainable Agriculture.

Krull, E., Singh, B. and Joseph, S. (2010). Preface to special issue: proceedings from the First Asia- Pacific Biochar Conference, 2009, Gold Coast, Australia', Australian Journal of Soil Research 48(6–7): i–iv.

Kwapinski, W., Byrne, C.M.P., Kryachko, E., Wolfram, P., Adley, C., Leahy, J.J., Novotny, E.H. and Hayes, M.H.B., (2010). 'Biochar from biomass and waste', Waste Biomass Valor 1: 177–89.

Laird, D.A., Fleming, P., Davis, D.D., Horton, R., Wang, B. and Karlen, D. (2010). Impact of biochar amendments on the quality of typical Midwestern agricultural soil. Geoderma, 158: 44– 449.

Lang, T., Jensen, A.D. and Jensen, P.A. (2005). 'Retention of organic elements during solid fuel pyrolysis with emphasis on the peculiar behavior of nitrogen', Energy and Fuels 19: 1631–43.

Lehmann, J., Gaunt, J. and Rondon, M. (2006). Biochar Sequestration in terrestrial ecosystem- a review. Mitigation and Adoptation Strategies for Global Change 11:403-427.

Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C., and Crowley, D. (2011). Biochar effects on soil biota – A review. Soil Biology and Biochemistry, 43: 1812 – 1836

Lehmann, J. and S., Joseph (2009). Biochar for Environmental Management: Science and Technology. Earthscan, London & Sterling, VA. 416p.

Lehmann, J., Solomon, D., Kinyangi, J., Dathe, L., Wirick, S., Jacobsen, C. (2008). Spatial complexity of soil organic matter forms at nanometre scales. Nature Geoscience 1, 238-242.

Liang, B., J., Lehmann, D., Solomon, J., Kinyangi, J., Grossman, B., O'Neill, J. O., Skjemstad, J., Thies, F. J., Luizao, J., Petersen and E. G., Neves (2006). Black carbon increases cation exchange capacity in soils. SSSA J. 70: 1719-1730

Major, J., Rondon, M., Molina, D., Riha, S. J. and Lehmann, J. (2010). Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. Plant and Soil 333: 117-128

Marris E. (2006). Black is the new green. Nature 442(10):469–624.

Marschner, H. (1995). Mineral nutrition of higher plants. 2nd ed. Academic Press, San Diego, CA.

Mbagwu, J.S.C. and Piccolo, A. (1997). Effects of humic substances from oxidized coal on soil chemical properties and maize yield. In: Drozd, J., Gonet, S.S., Senesi, N., Weber, J. (eds). The role of humic substances in the ecosystems and in environmental protection. IHSS, Polish Society of Humic Substances, Wroclaw, Poland, pp 921–925.

McHenry, M.P. (2009). Agriculture biochar production, renewable energy generation and farm sequestration in Western Australia: certainty, uncertainty and risk. Agriculture, Ecosystem and Environment. 129:1-7.

Moses, H.D., Gua, S. and Hagan, E.B. (2011). Biochar Production in Ghana- Renewable and Sustainable Energy Reviews (15) 3539– 3551.Elsevier

Navia, R. and Crowley, D.E. (2010). Closing the loop on organic waste management: biochar for agricultural land application and climate change mitigation, Waste Management and Research 28(6): 479–80.

Novak, J.M., Busscher, W.J., Laird, D.L., Ahmedna, M., Watts, D.W. and Niandou, M.A.S. (2009). Impact of biochar amendment on fertility of a southeastern coastal plan soil. Soil Science, 174: 105 – 112.

Oades, J.M. (1993). The role of biology in the formation, stabilization and degradation of soil structure. Geoderma, 56: 377-400.

Oguntunde, P.G., Fosu M, Ajayi, A.E., van de Giesen, N. (2004). Effect of charcoal production on maize yield, chemical properties and texture of soil. Biol Fertil Soils. 39: 295-299.

Oldeman, L.R. (1994). The global extent of soil degradation. In: Greenland D.J., Szaboles T, eds. Soil Resilience and Sustainable Land Use. Wallingford: CAB International.

Pandey, A. (2009). Handbook of plant-based biofuels. 1st ed. CRC Press, Florida, USA.

Pastor-Villegas, J., Pastore-Valle, J.F., Meneses Rodríguez, J.M. and García, M. (2006). Study of commercial wood charcoals for the preparation of carbon adsorbents', Journal of Analytical and Applied Pyrolysis, 76: 103 – 108.

Peng, X., Ye, L.L., Wang, C.H., Zhou, H. and Sun, B. (2011). Temperature and duration dependent rice straw-derived biochar: Characteristics and its effects on soil properties of an Ultisol in southern China. Soil and Tillage Research, 112.

Pratt, K. And Moran, D. (2010). Evaluating the cost-effectiveness of global biochar mitigation potential. Biomass and Bioenergy, 34: 1149 – 1158.

Quaye, K., Hall, C.A.S. and Luzady, V.A. (2010). Agricultural land use efficiency and food crop production in Ghana. Environment and Sustainable Development, doi: 10.1007/s10668-010-9234.

Qureshi, J. N. (1991). The cumulative effects of N–P fertilizers, manure and crop residues on maize and bean yields and some soil chemical properties at Kabete. P. 160-167. In Recent advances in KARI'S research programmes. Kenya Agricultural Res. Institute, Nairobi, Kenya

Reich, P.F., Numbem, S.T., Almaraz, R.A., Eswaran, H. (2001). Land resource stresses and desertification in Africa. In: Bridges E.M., Hannam I.D., Oldeman L.R., Pening, F.W.T., de Vries, S.J., Scherr, S.J., Sompatpanit, S. eds. Responses to land degradation. Proceedings of the 2nd International Conference on Land Degradation and Desertification, Kon Kaen, Thailand. New Delhi: Oxford Press.

Roberts, K.G., Gloy, B.A., Joseph, S., Scott, N.R. and Lehmann, J. (2010). 'Life cycle assessment of biochar systems: estimating the energetic, economic, and climate change potential', Environmental Science and Technology 44: 827–33.

Rondon, M.A., Lehmann, J., Ramirez, J. and Hurtado, M. (2007). Biological nitrogen fixation by common beans (Phaseolus vulgaris L.) increases with biochar additions. Biology and Fertility of Soil, 43: 699 – 708.

Rowell, D. L. (1993). Soil Science: Methods and Applications. Department of Soil

Sanders, J., H., Shapico, B.I. and Ramaswamy, S. (1996). The economics of agricultural technology in semi-arid sub-Saharan Africa. John Hopkins University Press, Baltimore, MD, USA. 303p. Sasseville, D. N.

Savannah Agricultural Research Institute (2004). Annual report for the year 2004, Nyankpala. P.22.

Shackley, S.J. and Sohi, S.P. (2010). An assessment of the benefits and issues associated with the application of biochar to soil, Department for Environment, Food and Rural Affairs, London, UK.

Sims, R.E.H. (2002). The brilliance of bioenergy in business and in practice. 1st ed. James and James, London, UK.

Singh, B.P., Hatton, B.J., Singh, B., Cowie, A.L. and Kathuria, A. (2010). 'Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils', Journal of Environmental Quality 39: 1224–35.

Six, J., Bossuyt, H., Degryze, S. and Denet, K. (2004). A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil and Tillage Research, 79: 7– 31.

Sohi, S.P., Lopez-Cali, E., Krull, E. and Bol, R. (2009). Biochar, climate change and soil: A review to guise future research. CIRO Land and Water Science

Sohi, S.P., Krull, E, Lopez-Capel, E. and Bol, R. (2010). 'Chapter 2–A review of biochar and its use and function in soil', Advances in Agronomy 105: 47–82.

Sombroek, W., Ruivo, M.L., Fearnside, P.M., Glaser, B. and Lehmann J. (2003). Amazonian Dark Earths as carbon stores and sinks. In J. Lehmann, D.C., Kern, B., Glaser, and W.I., Woods (eds.). Amazonian Dark Earths: Origin, Properties, Management, (pp. 125–139) Dordrecht, Kluwer Academic Publishers.

Steiner, C., Glaser, B., Teixera, W.G., Lehmann, J., Blum, W.E.H. and Zech, W. (2008). Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. Journal of Plant Nutrition and Soil Science, 171: 893 – 899.

Swift, M. J., Seward, P. D., Frost, P. G. H., Qureshi, J. N. and Muchena, F. N. (1994). Long-term experiments in Africa: developing a database for sustainable land use under global change. P. 229 - 251. In: R. A., Leigh and A. E., Johnson (ed.) Long-term experiments in agricultural and ecological sciences. CAB International, Wallingford, UK.

Thies, J.E., and Rillig, M.C. (2009). 'Characteristics of Biochar: Biological Properties', in Lehmann, J & Joseph, S, and Biochar for environmental management: science and technology, Earthscan, United Kingdom, 85–105

Van Zwieten, L., Sigh, B., Joseph, S., Kimber, S., Cowie, A., and Chan, K.Y. (2009). Biochar and emissions of non-CO2 greenhouse gases from soil. In: Lehmann, J.

& Joseph, S. (Eds.), Biochar for Environmental Management – Science and Technology, Earthscan, London: 227 – 247.

Van Zwieten, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., Joseph, S. and Cowie, A. (2010). Effects of biochar from slow pyrolysis of paper mill waste on agronomic performance and soil fertility. Plant and Soil, 327: 235 – 246.

Wardle, D.A., Nilsson, M.C., and Zackrisson, L. (2008). Fore-derived charcoal causes loss of forest humus. Science, 320: 692.

Yeboah, E., Ofori, P., Quansah, G.W., Dugan, E., Sohi, S.P. (2009). Improving soil productivity through biochar amendments to soils. African Journal of Environmental Science and Technology 3(2):34–41.

Zeelie, A. (2012). Effect of biochar on selected soil physical properties of sandy soil with low agricultural suitability.

APPENDIX

APPENDIX A

Maize plant height (cm) as influenced by biochar and inorganic fertilizer N during maize growth stages at Nyankpala

Treatment	Week after planting (WAP)			
	2	4	6	8
0t/ha biochar +0kgN	11.41	31.19	109.43	128.16
0t/ha biochar 30kgN	11.12	30.81	123.38	159.19
0t/ha biocha+60kgN	10.85	31.01	131.51	170.14
0t/ha biochar 90kgN	11.55	32.11	139.57	183.53
2t/ha biochar +0kgN	11.36	31.79	114.99	201.49
2t/ha biochar 30kgN	11.42	31.09	125.93	219.65
2t/ha biochar +60kgN	11.26	32.73	133.67	232.34
2t/ha biochar + 90kgN	11.97	32.93	141.60	244.25
4t/ha biochar +0kgN	12.95	32.21	137.30	255.70
4t/ha biochar + 30kgN	12.97	32.49	139.04	261.33
4t/ha biochar +60kgN	13.23	32.77	138.93	274.59
4t/ha biochar + 90kgN	13.88	33.62	144.00	287.22
LSD(P> 0.05)	ns	Ns	ns	ns
CV%	2.5	1.7	0.9	0.1

APPENDIX B

Maize girth (cm) as influenced by biochar and inorganic fertilizer N during growth stages at Nyankpala

Treatment	Week after planting (WAP)			
	2	4	6	8
0t/ha biochar +0kgN	5.80	8.87	10.00	11.27
0t/ha biochar + 30kgN	6.00	9.00	10.00	11.40
0t/ha biochar +60kgN	6.00	9.00	10.20	11.53
0t/ha biochar + 90kgN	6.00	9.00	10.20	11.73
2t/ha biochar +0kgN	6.00	9.00	10.13	12.00
2t/ha biochar + 30kgN	6.00	9.00	10.20	12.20
2t/ha biochar +60kgN	6.00	9.00	10.27	12.53
2t/ha biochar + 90kgN	6.00	9.00	10.33	12.73
4t/ha biochar +0kgN	6.00	9.00	10.40	13.00
4t/ha biochar + 30kgN	6.00	9.00	10.53	13.13
4t/ha biochar +60kgN	6.00	9.00	10.60	13.53
4t/ha biochar + 90kgN	6.00	9.00	10.93	14.33
LSD(P>0.05)	Ns	Ns	ns	ns
CV%	0.1	0.11	0.2	0.16

APPENDIX C

Maize girth (cm) as influenced by biochar and inorganic fertilizer N during growth stages at Nyankpala

Treatment	Week after planting (WAP)				
	2	4	6	8	10
0t/ha biochar +0kgN	1.05	4.17	4.43	4.90	3.73
0t/ha biochar +30kgN	1.10	4.23	4.52	5.50	4.33
0t/ha biochar +60kgN	1.17	4.19	4.55	5.69	4.17
0t/ha biochar +90kgN	1.31	4.41	4.59	5.97	4.87
2t/ha biochar +0kgN	1.11	4.23	4.49	6.27	5.11
2t/ha biochar +30kgN	1.19	4.37	4.56	6.60	5.18
2t/ha biochar +60kgN	1.35	4.31	4.56	7.03	5.37
2t/ha biochar +90kgN	1.33	4.37	4.56	7.24	6.06
4t/ha biochar +0kgN	1.37	4.34	4.58	7.50	6.15
4t/ha biochar +30kgN	1.37	4.30	4.59	7.67	6.32
4t/ha biochar +60kgN	1.37	4.35	4.61	7.90	6.69
4t/ha biochar +90kgN	1.43	4.45	4.70	8.19	7.14
LSD(P>0.05)	5.5	1.4	0.6	0.4	1.1
CV%	ns	ns	ns	ns	ns

APPENDIX D

Soil nutrient (mineral) content and interpretation

Nutrient	**Rank / Grade**
Soil pH (Distilled Water Method)	
< 5.0	Very Acidic
5.0 – 5.5	Acidic
5.6 – 6.0	Moderately Acidic
6.1 – 6.5	Slightly Acidic
6.6 – 7.0	Neutral
7.1 – 7.5	Slightly Alkaline
7.6 – 8.5	Alkaline
> 8.5	Very Alkaline
Organic Matter (%)	
< 1.5	Low
1.6 – 3.0	Moderate
> 3.0	High
Nitrogen (%)	
< 0.1	Low
0.1 – 0.2	Moderate
> 0.2	High

From Soil Research Institute (CSIR)

Soil nutrient (mineral) content and interpretation

Nutrient	Rank / Grade
Phosphorus, P (ppm) – Bray's No.1	
< 10	Low
10 – 20	Moderate
> 20	High
Potassium, K (ppm)	
< 50	Low
50 – 100	Moderate
> 100	High
Calcium, Ca (cmol (+) kg^{-1})	
< 5	Low
5 – 10	Moderate
> 10	High
Exchangeable Potassium (cmol (+) kg^{-1})	
< 0.2	Low
0.2 – 0.4	Moderate
> 0.4	High
ECEC (cmol (+) kg^{-1})	
< 10	Low
10 – 20	Moderate
> 20	High

APPENDIX E

Calculation of fertilizer rate

30kgN

Urea contains 46 %N

Therefore if 10,000m^2 = 30kg N

Then 40.96m^2 = xkg N

Xkg N = 40.96m^2 x 30kg N / 10,000m^2

Xkg N = 0.123kgN/ ha per subplot

Therefore if 100kg urea = 46kg N

Then xkg urea = 0.123kg N

100kg urea x 0.123kg N / 46kg N = 0.267kg urea per subplot

The total amount of urea to be applied for one block = 0.267kg urea x 3 = 0.81kg urea

The total amount of 30kgN urea to be applied for three (3) replications = 0.81 x 3 = 2.43kg urea

60kg N

If 10,000m^2 = 60kg N

Then 40.96m^2 = xkg N

Xkg N = 40.96m^2 x 60kg N / 10,000m^2

Xkg N = 0.245kgN/ ha per subplot

Therefore if 100kg urea = 46kg N

Then xkg urea = 0.245kg N

100kg urea x 0.245kg N / 46kg N = 0.5326kg urea per subplot

The total amount of urea to be applied for one block = 0.5326kg urea x 3 = 1.5978kg urea

The total amount of 60kg N urea to be applied for the three (3) replications =1.5978 x3 = 4.79334kg urea

<u>90kg N</u>

If 10,000m^2 = 90kg N

Then 40.96m^2 = kg N

Xkg N = 40.96m^2 x 90kg N / 10,000m^2

Xkg N = 0.37kgN/ ha per subplot

Therefore if 100kg urea = 46kg N

Then Xkg urea = 0.37kg N

100kg urea x 0.37kg N / 46kg N = 0.804kg urea

The total amount of urea to be applied for the whole plot = 0.804kg urea x 3 = 2.412kg urea

The total amount of 90kgN urea for the three (3) replications = 3x2.412kg urea = 7.236kg urea

<u>BASAL APPLICATION</u>

60kg P

10,000m^2 = 60kg P

Then 40.96m^2 = xkg P

Xkg P = 40.96m^2 x 60kg P / 10,000m^2

Xkg P = 0.246kgP/ ha per subplot

Therefore if 100kg P_2O_5 = 46kg P

Then xkg P_2O_5 = 0.246kg P

100kg P_2O_5 x 0.246kg P / 46kg P = 0.535kg P_2O_5

To get Pkg multiply 0.4363 by the value of P_2O_5

0.535kg P_2O_5 x 0.4363 = 0.233kg P/ ha

The total amount of P to be applied for the whole plot = 0.233kg P x 3 = 0.699kg P/ha

The total amount of P to be applied for the three (3) replications = 3 x 0.699kgP = 2.097kgP

60kg K

10,000m^2 = 60kg K

Then 40.96m^2 = Xkg K

Xkg K = 40.96m^2 x 60kg K ⁄ 10,000m^2

Xkg K = 0.25kgK/ ha per subplot

Therefore if 100kg K_2O = 60kg K

Then Xkg K_2O = 0.25kg K

100kg K_2O x 0.25kg K / 60kgK = 0.42kg K_2O

To get K kg multiply 0.8301 by the value of K_2O

0.42kg K_2O x 0.8301 = 0.348kg K/ ha

The total amount of K to be applied for the whole plot = 0.348kg K x3 = 1.044kg K/ha

The total amount of K to be applied for the three (3) replications = 1.044kgK x 3 = 3.132kgK

Total amount of urea used = 2.43+4.79334+7.236 = 14.459Kg

Total amount of k_2o used = 3.132kg

Total amount of tsp = 2.097kg

Calculation of biochar rates

2t/ha biochar

10000m^2 = 2000kg biochar

40.96m^2 = Xkg biochar

Xkg biochar = 40.96m^2 x 2000kg biochar /10000m^2

Xkg biochar = 8.2kg

The total amount of 2t/ha biochar to be applied at replication one = 8.2kg x 4(number of subplots) = 32.8kg

The total amount of 2t/ha biochar to be applied at three replications =32.8kg x 3

= 98.3kg (2 bags)

4t/ha biochar

$10000m^2$ = 4000kg biochar

$40.96m^2$ = Xkg biochar

Xkg biochar = $40.96m^2$ x 4000kg biochar /$10000m^2$

Xkg biochar = 16.4kg

The total amount of 4t/ha biochar to be applied at replication one = 16.4kg x 4(number of subplots) = 65.54kg

The total amount of 4t/ha biochar to be applied at three replications =65.54kg x 3

= 196.61kg (4 bags)

Therefore the total amount of biochar used = 6 bags (50kg/bag)

APPENDIX F

QUESTIONNAIRE

ASSESSMENT OF BIOCHAR FEEDSTOCK AND THE PROSPECTS OF ITS USE IN NYANPKALA

Identifiers

1. Respondent's name
……………………………………………………………………………..
2. Interviewer name
……………………………………………………………………………..
3. Community
……………………………………………………………………………........................
4. Date: [ ][ ] [ ][ ] [ ][ ][ ][ ]
dd mm yyyy

Demographics

5. Sex 1. Male [ ] 2. Female [ ]
6. Age (yrs) [ ]
7. Educational Level Primary 1[ ] JHS 2 [ ] SHS 3[ ] Tertiary 4 [ ]

Knowledge

8. Have you ever heard of Biochar?
1. Yes [ ] 2. No [ ] 3. Don't know [ ]

9. If yes, where did you hear it from?
1. Media [ ] 2. Friends or family members [ ] 3. Extension officer [ ] 4. Other(s), specify……….

10. What do you know about biochar?
…………………………………………………………………………………………………
11. Are you prepared to use biochar for crop production?
1. Yes [ ] 2. No [ ] 3. Don't know [ ]
12. Why?
....
13. What are the crops you cultivate?...……………………………………………………………
14. What are the quantities (bags) of produce obtained per hectare after harvest?
…………………………………
15. What are the by-products of the crops you grow?…………………………………………………………………………

16. What do you use the by-product (s) for?
………………………………………………………………………………………………
…
17. Will you prefer using the by-product (s) for biochar?
1. Yes [ ] 2. No [ ] 3. Don't know [ ]
18.Why?..
....
19. Are there any waste products from the harvested crops?
1. Yes [ ] 2. No [ ] 3. Don't know [ ]
20. If yes, what are they?
…..……………………………………………………………………………………………
……………………………
21. What do you use the waste material for?
……………………………………………………………………………………………..
22. Will you prefer using the waste materials for biochar?
1. Yes [ ] 2. No [ ] 3. Don't know [ ]
23. If yes, why?
………………………………………………………………………………………………
……………………………………………
24. If no, why?
…...
...
25. Will you prefer using biochar for crop production?
1. Yes [ ] 2. No [ ] 3. Don't know [ ]
26. If yes, why?
………………………………………………………………………………………………
……………………………………………
27. If no,
why?...
....
28. What crops will you prefer to cultivate when you are using biochar?
…………………………………………………
29. Will you pay for biochar if found to improve crop yield?
1. Yes [ ] 2. No [ ] 3. Don't know [ ]
30. If yes,
why?...
....
31. If no, why?
....
..
32. Which would be your preference for agriculture (crop production) ?
1. Biochar [ ] 2. Fertilizer (inorganic fertilizer) [ ]
33. Why?
....
....