UNIVERSITY OF CAPE COAST

EVALUATION OF LOCAL FEEDSTOCKS FOR BIOCHAR PRODUCTION AND POTENTIAL USE OF IT AS SOIL AMENDMENT FOR LETTUCE (*Lactuca sativa*.L) PRODUCTION

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BY

KOFI ATIAH

Thesis submitted to the Department of Soil Science of the School of Agriculture, University of Cape Coast, in partial fulfillment of the requirements for award of Master of Philosophy Degree in Land Use and Environmental Science

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DECLARATION

Candidate's Declaration

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

Candidate's Signature:…… Date: ……

Name: Kofi Atiah

Supervisors' Declaration

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

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

Name: Prof. Benjamin A. Osei

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

Name: Prof. Peter K. Kwakye

ABSTRACT

Agricultural waste can be processed under pyrolysis to generate energy for cooking, resulting in a byproduct called biochar. Biochar has the potential to be used as a soil amendment but this facility has not been explored by researchers. Unpelletized corn cob and oil palm press were subjected to water boiling test, burning duration test, biomass consumption rate, biochar yield, pH of residual water and flame characteristics using Lucia stove. The results generally indicated that corn cob feedstock did better than oil palm press in the parameters assessed.

The completely randomized design was used in experiment two to four to assess corn cob biochar effect on growth and yield of lettuce. Six treatments and four replications of biochar were used in a pot trial on an Oxisol. Biochar rates applied were 0 %, 1 %, 2 %, 3 %, 4 % and 5 %. Biochar additions showed significant differences on height and total dry matter but not on number of leaves at maturity ($P > 0.05$). In experiment three, the biochar was combined with three levels of poultry manure (PM) at 2.5, 5 and 10 t ha^{-1} with four replications. There were significant increases in height, number of leaves and on total dry matter ($P < 0.05$).

Among the treatments, 3 % (78 t ha^{-1}) biochar with 10 t ha^{-1} of PM gave superior response on growth and yield of lettuce. In experiment four biochar applied to soil increased pH, available P, total nitrogen, ECEC, exchangeable Mg^{+2} and K^{+}; reduced exchangeable acidity, compared to the control. The results indicate that the biochar generated may serve as a useful liming material on the acidic Oxisol.

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DEDICATION

To my better half, Ramatu and my children Ajaasuma, Najeeba and Nabeeha

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CHAPTER ONE

GENERAL INTRODUCTION

Biomass is the main source of energy in many households in Sub-Saharan Africa (Ndiema, et al., 1998). Traditional small-scale combustion of biomass degrades air quality, and is thermally inefficient, but the high cost of cleaner substitutes such as liquefied petroleum gas (LPG) and their unavailability in many communities make rapid shifts away from the use of the traditional fuels unlikely. Thus, majority of low income populations are likely to continue using biomass fuels as energy source for cooking (Ahuja et al., 1987). The 2010 population and housing census carried out by the Ghana Statistical Service, revealed that majority of Ghanaians still relied on solid fuel as their main source of energy for cooking: wood (55.8 %), charcoal (30 %) and others which include electricity, gas and kerosene (9.3 %). However, due to the poor or low burning efficiencies of the kind of swish stoves that are prevalent in most homes in the Least Developed Countries (LDCs) including Sub-Saharan Africa (SSA), there is high level production of particulate matter (PM), carbon monoxide (CO), oxides of nitrogen (NO_x) as well as carbon dioxide (CO_2), all of which have health implications for women and children (UNDP & WHO, 2009). A number of improved biomass fired stoves have been deployed in different countries with the aim of overcoming the two major drawbacks of traditional stoves, which are low efficiency and indoor air pollution. In addition, these stoves use crop residues, which will help ease the

pressure on our forests for fuel wood. However, the sustainability of these biomass fired stoves in terms of adoption and acceptability by users would greatly depend on the stoves efficiency regarding cooking duration per amount of biomass input, reduction in smoke, ease of operation as well as its versatility to varying sources of biomass. Again, the biochar produced as a by-product of biomass burning through pyrolysis can be used to improve soil fertility.

Africa's population continues to grow at higher rates than on any other continent (Sanchez et al., 1997), and soil fertility depletion is considered as the major biophysical factor limiting per capita food production on the majority of African smallscale farms (Sanchez et al., 1997). With economies mostly dependent on agriculture, especially in Eastern, Western, and Central Africa, soil degradation is a major threat to overall economic development (Scherr, 1999). Moreover, not much information is currently available in the literature regarding combined applications of biochar and organic manure, and their effects on crop yields on heavily weathered Ghanaian soils.

Statement of Problem

According to the United Nations Development Programme (UNDP) and the World Health Organization (WHO) report of 2009, two billion people will need modern energy services by 2015 to accelerate the achievement of the Millennium Development Goals (MDGs). Again, in Least Developed Countries (LDCs) and Sub Saharan Africa (SSA), more than 80 percent of people primarily rely on solid fuels such as wood and charcoal for cooking, compared to 56 percent of people in developing countries as a whole (UNDP & WHO, 2009). Open burning of these solid fuels using inefficient swish

stoves leads to heavy smoking and this leads to indoor air pollution which causes deaths due to unventilated kitchens. Among these deaths, some 44 percent are children; and among adult deaths, 60 percent are women (UNDP & WHO, 2009).

Biochar application has come as one of the emerging or major means of agriculturally sequestering carbon in to the soil to help in part to reducing global warning, hence climate change, through the sequestering of CO_2 in to the soil in the form of carbon (C) which is recalcitrant to decomposition by soil microbes (Kimetu et al., 2010).The incorporation of biochar materials tends to improve the physical and the chemical properties of soils (Verheijen et al., 2009).

Justification

In SSA, more than 50 percent of all deaths from pneumonia in children under 5 years and chronic lung disease and lung cancer in adults over 30 years can be attributed to solid fuel use (UNDP & WHO, 2009). However, access to improved cooking stoves is also very limited**.** In LDCs and SSA, only seven percent of the people who rely on solid fuels use improved cooking stoves to help reduce indoor smoke, compared to 27 percent of people in developing countries as a whole, implying the need to increase the use of improved biomass stoves in the LDCs.

Soils in Sub-Saharan Africa are characterized by high acidity, low cation exchange capacities (CEC), low organic matter content, low activity clay minerals, as well as reduced activities of vital soil microbes. All these characteristics are as a result of the interplay of driving forces such as heavy rainfall, high temperatures, poor crop cover, nutrient mining, which is peculiar

to the tropics. In Ghana, farming is the main occupation providing jobs to 55.8 % of the Ghanaian workforce (Ghana Statistical Service, 2008). The very existence of these farmers is under threat due to the decline in the productivity of the soil. However, the low pH of these soils can be increased by the addition of biochar, which will not only increase pH, but also improve the nutrient retention, increase the water holding capacity, and overall, ameliorate the conditions of these tropical soils. These biochar materials could be locally obtained since it will be a by-product of fuel energy to stoves for cooking, as compared to farmers relying on liming materials which most of the time are either not readily available or not affordable, in most cases. It should also be noted that conversion of biomass C to bio-char C leads to sequestration of about 50 % of the initial C compared to the low amounts retained after burning (3 %) and biological decomposition (<10–20 % after 5–10 years), therefore yielding more stable soil C than burning or direct land application of biomass (Lehmann et al., 2006).

The existence of the Amazonian Dark Earths (ADE) proves that infertile Oxisols can in principle be transformed into fertile soils. However, this transformation is not solely achieved by replenishing the mineral nutrient supply, but relies on the addition of stable C in the form of charcoal. The sustained fertility in charcoal-containing ADE and the frequent use of the charcoal as soil conditioner in Brazil (Steiner et al., 2004b) and other parts of the world, (Ogawa, 1994), provided the incentive to study the effects of charcoal application to a highly weathered soil (Lehmann et al., 2003). Therefore, biochar addition in combination with organic manure could be an alternative to merely adding organic and inorganic fertilizers, and this could be

an important step toward sustainability of soil organic matter (SOM) conservation in tropical agriculture.

Hypotheses

The hypotheses which formed the basis of the study were:

Ho: the feedstocks do not differ in burning duration, biomass consumption rate, biochar yield, boiling duration, pH of residual water and flame characteristics being assessed on the stove

Ha: the feedstocks do differ in burning duration, biomass consumption rate, biochar yield, boiling duration, pH of residual water and flame characteristics being assessed on the stove.

Ho: biochar treatments alone do not have any effect on soil pH, organic carbon, organic nitrogen, available phosphorus, exchangeable calcium, magnesium and potassium, exchangeable acidity and effective cation exchange capacity of the soil.

Ha: biochar treatments alone have effects on soil pH, organic carbon, organic nitrogen, available phosphorus, exchangeable calcium, magnesium and potassium, exchangeable acidity and effective cation exchange capacity of the soil

Ho: biochar either alone or in combination with poultry manure does not have effect on height, leaf number at maturity and on total dry matter yield of lettuce.

Ha: biochar either alone or in combination with poultry manure have an effect on height, leaf number at maturity and on total dry matter yield of lettuce.

General objective

The main aim of this research was to assess the performance of lucia stove using locally available plant biomass as feedstocks and examine the relative effectiveness of corn cob biochar as a soil amendment.

Specific Objectives

The specific objectives were to:

1. Evaluate the lucia stove with local feedstocks to ensure sustained and efficient use of the stove.
2. Characterize the biochar produced through the pyrolysis process.
3. Evaluate the effect of the use of biochar as a soil amendment on the growth and yield of lettuce (*Lactuca sativa.* L).
4. Evaluate the impact of combined application of biochar and poultry manure on the growth and yield of lettuce (*Lactuca sativa.* L).
5. Evaluate the residual effect of biochar amendment on some chemical properties of the soil.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter provides a review on the concept and definition of biochar. However, mention is also made of the concept of microgasifier with a brief history of its adoption as a cookstove. In addition, it seeks to explore biomass utilization and its environmental impact with skewness towards the energy situation in Ghana. The last part of this chapter discusses the effect of biochar applications on the yield of crops and on some selected soil chemical properties.

Brief History of Microgasifiers

Commercially viable gasifiers have long been understood and used in large industry and even in transportation: over one million vehicles were fueled by biomass (mainly charcoal) gasification during World War II, when liquid fuel was hard to come by (Christa, 2011). The journey towards the development of a microgasifier was an uneasy one largely due to the very high temperatures needed to transfer heat to cold biomass; hence making gasifiers exceptionally smaller for home use was a daunty one.

Concept and Definition of Microgasifier

Micro-gasification refers to gasifiers small enough in size to fit under a cooking pot at a convenient height. It was conceptualised as a top-lit up-draft (abbreviated TLUD) process in 1985 and developed to laboratory prototype

stages by Dr. Thomas B. Reed in the USA. Independently in the 1990s the Norwegian Paal Wendelbo developed stoves based on the same TLUD principle in refugee camps in Uganda. TLUD devices have always been intended as biomass-burning cook-stoves and there were some early Do-It-Yourself backpacker efforts, but it was only in 2003 that the first micro-gasifier was commercially made available by Dr. Thomas B. Reed when he presented the Woodgas Campstove to the outdoor camping niche market in the USA.

History of Improved Cook Stove Programmes

In industrial countries, the switch to more efficient stoves took place smoothly as fuel wood prices increased and stove makers increased efforts to build more efficient models. This was followed by a transition to cleaner fuels for cooking, such as coal and petroleum-based fuels.

As the availability of and access to petroleum-based fuels began to increase at the beginning of the 20th century, many urban households in developing countries switched to stoves using oil-based products such as kerosene or LPG as fuels, just like their developed nation counterparts. On the other hand, rural households continued their dependence on the burning of biomass fuels for cooking and heating purposes. This was mainly due to weak delivery channels for petroleum-based products and rural people's inability to afford these fuels especially compared to biomass resources, which were more freely available (Barnes et al., 1994). When oil prices increased in the 1970s, even urban households found it hard to pay for fuels such as kerosene and LPG and many of them stepped back down the energy ladder and started using biomass fuels for household energy.

Domestic cooking makes up a major portion of the total energy used in developing nations, close to 60 % in Sub-Saharan Africa, so that nearly three billion people worldwide cook their meals on simple stoves that use biomass fuels (Kammen, 1995). The goal of improved cook stove programs is to develop "more efficient, energy-saving, and inexpensive biomass cook stoves, that can help alleviate local pressure on wood resources, shorten the walking time required to collect the fuel, reduce cash outlays necessary for purchased fuel wood or charcoal, and diminish the pollution released to the environment"(Barnes et al., 1994).

One of the first improved stoves was the "Magan Chula", introduced in India in 1947. A publication called "Smokeless Kitchens for the Millions" (Raju, 1961) advocating the health and convenience benefits of increasing efficiency in the burning of biomass further stimulated the promotion of improved cook stoves. The initial wave of cook stove programs focused on the health aspects of such interventions. The general objective was to uplift the living conditions of the poor in the developing world (Karekezi & Rahja.1997).

Attention subsequently shifted to the potential for saving biomass fuels and limiting deforestation. Currently, there is a refocus on the health-related aspects of improved cook stove programs, as the benefits of moving from traditional stoves to improved ones are increasingly stressed by public health specialists. In addition, factors such as cooking comfort, convenience, and safety in the use of the stoves are starting to get incorporated into programme design (Regional Wood Energy Development Programme).

Energy Situation in Ghana

The usage pattern for energy in Ghana is similar to that of many developing countries. Traditional fuels such as firewood and charcoal provide the bulk of energy needs followed by petroleum and then electricity. As a developing tropical country, the majority of Ghana's energy use is in the home rather than in industry. There is no home heating requirement and energy use in the home is primarily for cooking and lighting. It is estimated that about 84 % of households in rural Ghana use fuel-wood in its untransformed state as their source of fuel. A further 13 % depend on charcoal as their fuel of choice for cooking. All other sources, for example, electricity, kerosene and LPG, together account for less than 3 % of consumption and are therefore relatively insignificant (Amissah-Arthur and Amonoo, 2004). These data suggest that most Ghanaians either in the urban or rural setting still depend largely on biomass fuel as their energy source for home cooking. To confirm this, a report by Amissah-Arthur and Amonoo in 2004 on a study of the social and poverty impacts of energy interventions on rural communities in Ghana indicated that in rural Ghana, charcoal use accounts for 61 % of the fuel, fuel-wood 25 %, liquefied petroleum gas (LPG) 10 % with 4 % representing electricity, kerosene and crop residue.

Biomass Utilization and Environmental Impact

The impact of reliance on fuel-wood and charcoal as energy source for cooking in both rural and urban settings could be heavy and diverse. Firstly, one needs to look at the larger picture regarding the environmental impact especially deforestation. It is estimated that 90 % of the world's fuel-wood is produced and used in the developing countries (Richard et al., 2002). The

most common method of cooking in these countries, particularly in the rural areas is on an open fire (three stones) stove. Three stone stoves are highly inefficient in cooking processes. This inefficiency of cooking methods coupled with a high population growth rate of the developing countries has led to an extensive deforestation all over the world.

The consequences of deforestation are multidirectional and interconnected. Some of the consequences are: the overall productivity of the land would be reduced, biodiversity will greatly diminish, soil is prone to erosion and drying, change in hydrological cycle as water drains off the land instead of being released by transpiration or percolating into ground water, a major CO_2 sink would be lost (removal of CO_2 from the air), people who depend on harvesting forest products will lose their livelihood and the overall reduction in wood and wood products (Yohannes, 2011).

The second most important aspect on the reliance of fuel-wood as energy source for home cooking in countries of the developing world is indoor air pollution and health. Among the pollutants produced from biomass combustion, the most common one are particulate matter (PM), carbon monoxide (CO), hydrocarbons (CH_x), nitrogen oxides and sulfur oxides (Karekezi & Rahja, 1997). From the health point of view, the most important pollutant is CO since even in low concentrations it is a very potent poison. It interferes with the oxygen-carrying capacity of the blood thereby depriving the body tissues from the much needed oxygen. Symptoms of acute CO poisoning are headaches, drowsiness and loss of consciousness. Prolonged exposure may lead to physiological disturbances such as reduced blood pH and reduced birth weights of infants (WHO, 1992).

Biochar and its Preparation

Biochar has been produced in varying ways and in most cases the final user may give the meaning and its definition. Based on this, biochar has been given the concepts and definitions as explained below.

Biochar is a product of thermal decomposition of biomass produced by the process called pyrolysis. Biochar has been found to be biochemically recalcitrant as compared to un-charred organic matter and possesses considerable potential to enhance long-term soil carbon pool (Lehmann et al.,. 2006). Biochar has been shown to improve soil structure and water retention, enhance nutrient availability and retention, ameliorate acidity, and reduce aluminium toxicity to plant roots and soil microbiota (Glaser et al., 2002).

Biochar is commonly defined as charred organic matter, produced with the intent to deliberately apply to soils to sequester carbon and improve soil properties (Lehmann & Joseph, 2009). Biochar is a carbon-rich solid material produced by heating biomass in an oxygen-limited environment and is intended to be added to soils as a means to sequester carbon (C) and maintain or improve soil functions and charcoal is in its utilitarian intention; charcoal is produced for other uses such as heating than biochar. In a physicochemical sense, biochar and charcoal are essentially the same material.

Physicochemical Properties of Biochars

The physical and chemical properties of biochar are mainly determined by the feedstock type and the pyrolysis operational conditions. It should be noted that feedstock heterogeneity and the wide range of chemical reactions that take place during pyrolysis results in biochars with unique structural and chemical characteristics (Antal and Gronli, 2003; Demirbas, 2004). This

review stresses on some selected characteristics that are likely to impact on soil properties and processes upon biochar incorporation into soil.

Structural, Chemical Composition and Surface Chemistry of Biochars

Structural Composition

The structures of most biochars are greatly influenced by the pyrolysis temperature and the feedstock composition. With earlier biochar researches done using lignocellulosic materials, the first component that undergoes thermal degradation is cellulose and this takes place between temperatures of 250 °C and 350 °C mainly through loss of volatile matter leaving behind amorphous C matrix. It is, however, worthy of note that some ealier researches were done with feedstocks such as tree back, crop residues- bargasse, olive waste (Yaman, 2004), chicken litter (Das et al., 2008; Chan et al., 2008), sewage sludge (Shinogi et al., 2002) and paper sludge. The increase in amorphous carbon leads to increases in aromaticity which also leads to increase in biochar stability or its recalcitrance when applied to soil. This increase in aromaticity is usually achieved through increase in pyrolytic temperature due to losses in volatile matter (Baldock & Smernik, 2002; Dermibas, 2004).

Chemical Composition and Surface Chemistry of Biochars

Biochar contains both stable and labile components making it highly heterogeneous (Sohi et al., 2009). According to Antal and Gronli (2003), the major constituents are carbon, volatile matter, mineral matter (ash) and moisture. Brown (2009) indicated that the relative proportion of these components is a determiner on its chemical and physical behaviour and function. This physical and chemical behaviour also determines biochar

suitability for a site specific application as well as transport and fate in the environment (Downie et al., 2009). It has been observed that biochars produced from crop residues are less robust and finer; however, they are also nutrient-rich and therefore more readily degradable by microbial communities in the environment (Sohi et al., 2009). The ash content of biochars is also found to be largely dependent on the feedstock (Verheijen et al., 2009). Crop residues and manures generally produce biochars with high ash contents, in contrast to that from woody feedstocks (Demirbas, 2004). According to Sohi et al. (2009), despite the production from a wide range of feedstocks and under varying pyrolysis conditions, it constantly has high carbon content and strong aromatic structure. They also attributed the stability of biochars in soils to these two features.

pH of Biochars

The pH of biochars is relatively homogenous, that is largely neutral to alkaline. Chan and Xu (2009) evaluated biochar pH values from a wide range of feedstocks and reported a mean of 8.1 from a range of 6.2 to 9.6. The latter authors further observed that the neutral pH values were recorded from biochar produced from tree backs and green waste where as the basic pH values came from biochar from poultry litter feedstocks. However, Chan et al. (2008) reported pH values of 9.9 and 13 for poultry litter biochars produced at 450 °C and 550 °C, respectively. These pH values are higher than those reported by Chan and Xu (2009). The differences observed might be due to the higher temperatures of pyrolysis which usually results in high ash content, eventually leading to increases in pH values as observed by Chan et al. (2009).

Total Carbon Contents of Biochars

The total carbon content of biochar range from 175 g kg^{-1} to 905 g kg^{-1} (Chan & Xu, 2009). Chan et al. (2008) produced two poultry litter biochars at temperatures of 450 °C and 550 °C and recorded total carbon of 380 g kg^{-1} and 330 g kg^{-1}, respectively. These low values recorded may be attributed to the feedstocks used since they were not from a lignocellulosic material. Agusalim et al. (2010) also reported total carbon contents of 334 g kg^{-1} and 438 g kg^{-1} for rice straw and rice husk biochars, respectively.

Total Nitrogen Contents of Biochars

Nitrogen levels from biochars have been shown to vary widely depending on final temperature of pyrolysis, heating rate, time of holding at final temperature, and type of feedstock (Amonette & Joseph 2009). While some researchers have indicated a low N content (Gaskin et al., 2008; Yao et al., 2010) and suggested that N is mostly present as heterocyclic N (so-called 'black N'; Knicker et al., 1996), others have observed considerable N content from chicken litter biochars (Chan et al., 2008), where it is mainly found as nitrate on the surface of the biochars. Ueno et al. (2007) reported values of 0.58, 0.45, 0.32 and 0.44 % for pyrolysis temperatures of 500, 600, 700 and 800 °C, respectively, for bargasse. From this study, it has been revealed that increasing pyrolysis temperature generally decreases the total nitrogen contents. This observation is attributed to nitrogen volatilization during pyrolysis of feedstocks. The source of feedstock also greatly influences the nitrogen content. Novak et al. (2009) reported total nitrogen contents of 0.34 % when they pyrolysed pecan shells at 700 °C. Busscher et al. (2010) reported a value of 0.4 % when he pyrolysed same feedstock at same

temperature. Similarly, Nguyen and Lehmann (2009) reported a total nitrogen content of 0.93 % and 0.92 % when they pyrolysed corn residues at temperatures of 350 °C and 600 °C, respectively. This indicates that regardless of the pyrolysis temperature, feedstock type influences the nitrogen contents of biochars.

C:N Ratios of Biochars

Atkinson et al. (2010), reported a range of C: N ratios which were between 7 and 759 for a wide range of feedstocks and pyrolysis temperatures ranging from 260 °C to 700 °C. Feedstock source plays an important role as far as the C: N ratios are concerned. Chan and Xu (2009) also reported C: N ratios of between 7 and 500 with an average of 61, from pyrolysis temperatures of between 350 °C and 500 °C. Feedstocks from corn residue had C: N ratios of 73 and 83 when pyrolysed at temperatures 350 °C and 600 °C, respectively (Nguyen & Lehmann, 2009). When Nguyen and Lehmann (2009) pyrolysed wood, *Quercus spp*, they reported C: N ratios of 759 and 739, for temperatures of 350 °C and 600 °C, respectively. Lima and Marshall (2005) reported C: N ratios of 34 and 29 when broiler litter and broiler cake were pyrolysed at temperature of 700 °C.

Total P Contents of Biochars

Phosphorus is mainly found in the ash fraction, with pH-dependent reactions and presence of chelating substances controlling its solubilisation (De Luca et al., 2009). Agusalim et al. (2010) reported a P value of 0.07 when rice husk was pyrolysed at temperature of 600 °C. Chan et al. (2007) reported a P content of 25 g kg^{-1} for poultry litter biochar produced at a temperature of 450 °C. Lima and Marshall (2005) reported a P content of 48 and 73 g kg^{-1} for

broiler litter and broiler cake pyrolysed at 700 °C. P content of wheat straw biochar varies from 0.45 and 2.10 g kg^{-1} (Chan & Xu, 2009).

Physical Properties of Biochars: Bulk Density

Increasing temperature during pyrolysis, leads to losses of volatile matter which results in dramatic increases in porosity and surface area (Bagreev et al., 2001). The bulk densities of biochars largely depend on the type of feedstock and the pyrolysis temperature. The bulk densities of biochars range from 0.3 and 0.43 Mg m^{-3} (Pastor-Villegas et al., 2006). In a review by Lehmann et al. (2011), they indicated that most published true biochar densities are high, ranging from 1.5 to 2.1 g cm^{-3}. However, Brewer et al. (2009) indicated that typical biochar densities lie between 0.09 and 0.5 g cm^{-3} values which are much lower than those of soils. Lehmann and workers attributed the higher values to inaccurate density measurements, which do not distinguish between true, solid particle density and the bulk density of the biochar particles plus their pore spaces.

Effects of Biochar on Soil Chemical Properties

Soils in the heavy rainfall zone of the tropics require the maintenance of crop productivity in the medium to long term. This phenomenon had mainly been attributed to intrinsic as well as anthropogenic factors. It has been reported that addition of biochar to sandy and nutrient- impoverished soils led to improvement and maintenance of soil productivity. Addition of biochar to soil causes changes in pH, electrical conductivity, CEC and nutrient levels (Liang et al., 2007; Gundale & DeLuca, 2007; Warnock et al., 2007; Amonette & Joseph, 2009).

Soil pH

The increases in soil pH induced by biochar additions are not surprising given the well documented use of material such as wood ash in modifying pH and nutrient availability, particularly P and K (Clarholm, 1997; Mahmood et al., 2003). Uzoma et al. (2011) reported significant increases in pH of a sandy soil with biochar rates of 0, 10, 15 and 20 t ha^{-1}. These rates, respectively, recorded pH values of 6.4, 7.1, 7.3, and 8.4 of an initial soil pH of 6.4. The increases in pH with increase in biochar rates translate to a significant positive linear relationship. Similar trend was also reported by Chan et al. (2007) when they investigated the agronomic value of green waste biochar as soil amendment. They observed that biochar applications of 0, 10. 50 and 100 t ha^{-1} resulted in soil pH values of 4.58, 4.61, 4.75 and 5.19 as against an initial soil pH of 4.5.

Soil available P

The application of biochar to sandy soils has been observed to increase in available P. As observed by Uzoma et al. (2011), application of biochar rates of 0, 10, 15 and 20 tons/ha led to increases in the levels of available P. The above rates resulted in available P of 0.12, 0.15, 0.18 and 0.16 g kg^{-1} for the above biochar rates, respectively; to an initial soil available P of 0.065 g kg^{-1}. They attributed the increases in P availability to high levels of P in the cow dung biochar as well as the increases in soil pH from 6.4 to 8.0, which also led to P availability. However, the reduction in P at the highest level of biochar application (20 t ha^{-1}) was attributed to P fixation with calcium as a result of pH increases towards alkalinity. The increase availability of P with

biochar applications was also observed by Chan et al. (2008) in a study involving the use of poultry litter biochar as soil amendment.

Soil Total Nitrogen

The incorporation of biochar to soils has been observed in literature to reduce ammonium leaching (Lehmann et al., 2003b; Major et al., 2009) and in some cases reduce N_2O emission (Spokas & Reicosky, 2009). These mechanisms that lead to reduction in N losses should contribute to increasing N in soils after biochar applications. The above observations was confirmed by Chan et al. (2008) when they observed increasing total N content of an Alfisol with increasing rate of biochar applications. It was revealed in their experiment that the soil with an initial N content of 0.23 % increased to 0.26, 0.28 and 0.33 % with biochar rates of 10, 25 and 50 t ha^{-1}, respectively. Increasing N content of soils with biochar applications was further confirmed by Chan et al. (2007). They reported a significant increase of N content of an Alfisol when its initial N content which was 1.3 g kg^{-1} increased to 1.7, 1.4, 1.5 and 1.6 g kg^{-1} for biochar rates of 0, 10, 25 and 100 t ha^{-1}, respectively.

Soil Organic Carbon

The recalcitrance of black carbon (BC) has been investigated by a lot of researchers (e.g. Glaser et al., 2002a; Lehmann et al., 2003; Rodon et al., 2007). Agusalim et al. (2010) observed an increase in soil organic carbon (SOC) upon application of rice husk biochar to rice cropping system in an acid sulphate soil. In their experiment, they observed that a soil with an initial SOC of 0.78 % increased to 4.09 % upon the application of 10 tons of rice husk biochar. This represents a percentage increase of 524 % over the unamended soil. Chan et al. (2007) also observed similar trend. They observed that a soil

with an initial SOC content of 18 g kg^{-1} was increased to 21.6, 27, 43.4 and 64.6 g kg^{-1} with biochar rates of 0, 10, 50 and 100 t ha^{-1}, respectively.

CEC of Biochar-applied Soils

The cation exchange capacity (CEC) of the soil is a measure for how well some nutrient (cations) are bound to the soil and, therefore, available for plant uptake and prevented from leaching to ground and surface waters (Verheijen et al., 2009). Uzoma et al. (2011) reported increasing CEC of soil with increasing biochar rates. They observed this when cow manure biochar was applied to a sandy soil with an initial CEC of 0.71 cmol $_c$ kg^{-1}. This was increased to 0.75, 0.92, 1.14, and 1.27 with biochar rates of 0, 10, 15 and 20 t ha^{-1}. The increase in the CEC of the soil with increasing rates of biochar was attributed to large surface area of the biochar and the corresponding negative charges. The increase in CEC with biochar additions was further confirmed by Chan et al. (2007). They observed this when green waste biochar was applied to an Alfisol with an initial CEC of 7.7 cmol $_c$ kg^{-1}. Biochar rates of 0, 10, 50 and 100 t ha^{-1} led to CEC increases of 8.42, 8.08, 9.10, and 10.6 cmol $_c$ kg^{-1}. The phenomenon of increase in CEC with biochar incorporation into soils could be due to the high surface negative charge resulting from oxidation of carboxylic and phenolic groups of biochar (Liang et al., 2006).

Biochar Application and Crop Yield

The application of biochar in combination with N and P fertilizers on two rice cultivars showed that grain yields increased with increasing biochar applications of 4 and 8 t ha^{-1} while biochar rates of 16 t ha^{-1} resulted in yields decline (Asai et al., 2009). These they attributed to increased N deficiencies resulting from the high C: N ratio of biochar.

CHAPTER THREE

GENERAL MATERIALS AND METHODS

Biochar Preparation

The biochar was obtained from a Lucia biomass pyrolytic stove at temperatures 300 °C and 350 °C, under low oxygen conditions. The feedstocks used to obtain the biochar were oil palm press and corn cob. Each type of biochar was ground, mixed thoroughly, oven-dried at 65 °C till constant weight and sieved through a 2.0 mm bronze sieve. These biochars were kept in a labelled polythene bags for laboratory analysis.

Biochar Characterization

pH Determination

Five grams of sieved biochar sample was weighed into a 50 ml centrifuge tube and 25 ml of distilled water added to obtain a biochar-water suspension ratio of 1: 5.5. These suspensions were shaken for 20 minutes using a mechanical shaker. The pH of each suspension was measured using a Jenway 3330 Research pH meter after it has been calibrated. Each biochar type pH was replicated three times and the values recorded.

Total Carbon Determination

The ashing method as described by Mclaughlin (2010) was followed. Five grams of each biochar sample was weighed in triplicates into a pre-weighed porcelain crucible. The crucibles were then placed into a pre-warmed furnace and temperature set at 550 °C and ashing left to complete overnight.

After cooling, the masses of each crucible plus ashes were weighed and recorded. This measurement for each sample was taken in triplicates. Total carbon determination was calculated as follows:

$$\% \quad C=\frac{W2-W3}{W1-W3} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad [1]$$

Where:

W1= wet weight of biochar and porcelain crucible (grammes)

W2= dry weight of biochar and porcelain crucible (grammes)

W3= weight of porcelain (grammes)

Total Nitrogen of Biochar using the Micro-Kjeldahl Method: Procedure

A sample of biochar weighing 0.2 g was digested with conc. H_2SO_4-H_2O_2 mixture in a Tecator Digestor 2012. A blank digest was also done. Twenty-five milliliters of the digest was distilled into a 100 ml conical flask containing 2 % boric acid. The distillate was titrated against a 0.0071 *M* HCI from green to pink. The total N content was determined using the formular below:

$$\%N=(S-B) \times T \times 14 \times 5 \times 100/200 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [2]$$

Where

S= volume of 0.0071M HCl used for sample titration

B= volume of 0.0071M HCl used for blank titration

T= molarity of HCl

14= atomic weight of nitrogen

5= sample dilution factor

200= sample weight in mg

100= factor for %

Total Phosphorus Determination

The method used here was the ascorbic acid method. There were three replicates. The digest and its contents were washed into 100 ml conical flasks as described in the determination of total nitrogen. A 5µg P ml^{-1}(ppm) of working standard was prepared from a 100 ppm stock solution of P. A 0, 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 ppm of P were prepared from 5µg P ml^{-1}(ppm) working standards by pipetting 0.5 ml, 1 ml, 2 ml, 3 ml, 4 ml, and 5ml into a 25 ml volumetric flask and 4 ml of reagent B was added and made to the mark with distilled water. The solution was allowed to stand for 15 minutes for blue colour development. To ensure homogeneity in treatment, 1 ml of aliquot of digest in the 100 ml conical flask were pipetted into the working standards. For the samples, 1 ml of aliquots were pipetted into various 25 ml volumetric flasks and 4 ml of reagent B (a solution containing ammonium molybdate and potassium antimony tartrate in ascorbic acid solution) was added to the sample aliquot and topped to the mark by addition of distilled water. The solutions were allowed to stand for 15 minutes for the development of the blue colour. The readings of the concentrations of phosphorus in both the working standards and samples were done using a spectrophotometer. Before the reading, the spectrophotometer (Spectronic 20) was heated up for 20 minutes. It was then calibrated by using the 0 ppm blank standard. Then, the readings of the working standards were taken at 880 nm wavelength. Readings were recorded and graphs of absorbance against working standards generated using micro soft office excel 2007. The absorbances of the various sample aliquots were immediately recorded. The concentrations of the samples were determined using the relations from the graph of absorbance against the

concentrations of the working standards. The linear relationship is expressed as y= mx+c. From the standards P concentrations and following the determination of their respective absorbances, the following linear relationship was established: y= 0.714x +0.006, where y is the absorbance in percent, x is the concentration of P in solution expressed as ppm or µg ml^{-1}, 0.714 is the gradient of the slope and the 0.006 is the y intercept. The final concentration of P in the various samples was then calculated using the equation as follows:

$$ppm\ of\ P\ in\ biochar =$$

$$ppm\ of\ P\ in\ solution \times \frac{vol\ of\ extractant(ml)}{weight\ of\ biochar(g)} \times \frac{final\ vol.of\ aliquot}{initial\ vol.of\ aliquot\ pipetted} \quad ..[3]$$

Total Potassium Determination

Potassium was determined from the H_2SO_4-H_2O_2 digest following a procedure as described by Stewarte *et al.* (1974). Before the flame photometer reading was done, the flame was made to equilibrate for 30 minutes and standards of potassium passed through the flame photometer for calibration. The concentration of K was determined by flame photometry. Readings were recorded in triplicates.100 ml contents were then passed through a flame photometer and readings done in triplicates. The final concentration of K in solution was determined using the formular below:

$$\%K = {}^{C}/_{100 \times wt} \quad \text{.....[4]}$$

Where;

C = concentration of potassium from emission curve

Wt = weight of soil in grammes

Site Description Location

The study was conducted on the Teaching and Research Farm of the School of Agriculture, University of Cape Coast. The site is located at an altitude of 22 m Mean Sea Level, Longitude 1° 18' 24" W and Latitude 5° 07' 40" N in the Central Region of Ghana (Ghana Geological Survey, 1960)

Climate

The rainfall distribution is bimodal with an annual mean of between 930 mm and 1200 mm (Abban, 1985). The major rainy season occurs from April to July with a short dry but cool spell in August. The minor season rain starts from September to November, which is subsequently followed by a dry period stretching from November to March (Benneh and Dickson, 1970). The relative humidity is generally high with night and early morning values of 99 % to 100 % and falling to about 70 % by mid-day (Meteorological Service Department, 1999).

Soil Sampling

Systematic stratified sampling technique was used to sample the soil. Stratification was based on the slope of the land. The field was partitioned into 4 sub-sites. The area of the sub-sites 1, 2, 3, and 4 were 374.7, 654.8, 489.9 and 824.6 m^2 respectively. Soil samples were taken in a zigzag pattern at a depth of 20 cm from each sub-site.

Sample Preparation

The soil samples were air-dried and passed through a 2 mm sieve to obtain the fine earth fractions. These were kept in labelled polythene bags for laboratory analyses. For the analysis of total N and total organic carbon, a sub

sample from the < 2 mm fraction was ground in a mortar and passed through a 0.15 mm sieve.

Soil Analyses

The analyses of soil samples were carried out between February 2011 and March 2011 in the Soil Science Laboratory of the University of Cape Coast. Soil chemical and physical parameters were determined.

Soil Chemical Properties

The soil chemical properties determined were total N, extractable P (Bray No.1), organic carbon, pH, exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}), exchangeable acidity (Al^{3+} and H^{+}) and effective cation exchange capacity (ECEC).

Total nitrogen was determined by the micro-Kjeldahl method as described by Stewart *et al*. (1974). The soil samples were digested with concentrated sulphuric acid on a tecator block digestor. The digest was distilled into conical flasks containing 2 % boric acid and was titrated against 0.01 M hydrochloric acid (HCl).

In the determination of extractable P, the method described by the International Institute for Tropical Agriculture (IITA, 1985) was followed. Soil extraction was by the Bray No.1 method. The soil was extracted with a 15 ml solution of 1.0 *N* ammonium fluoride (NH_4F) and 25 ml of 0.5 N HCl (Bray No.1 method). The extractable P in the aliquot was determined by the initial addition of 4 ml of a solution of ammonium molybdate and potassium antimony tartarate ($KSbOC_4H_4O_6$) after the dissolution of ascorbic acid (Ascorbic acid method). The P content was determined from the absorbance values on a spectrophotometer (Spectronic 20) at 880 nm.

The soil organic carbon was determined by wet oxidation with 0.1667 M potassium dichromate ($K_2Cr_2O_7$) solution and 20 ml of concentrated sulphuric acid (H_2SO_4) (Walkley and Black, 1934). The suspension was diluted with 200 ml of distilled water and 10 ml of 85 % phosphoric acid plus 0.2 g of sodium fluoride. With diphenylamine as indicator, the excess unreacted chromic ions in the soil samples were back titrated with 0.5 *N* ferrous sulphate solution. Readings were done in triplicates. The following formular was used to calculate soil organic carbon:

%OC=

$$(\text{me K2Cr2O7} - \text{me FeSO4}) \times 0.003 \times 100 \times \text{f/Sample weight(g)} =$$

$$\%OC = M \times (V1 - V2) \times 0.39 \times \text{mcf/Sample weight(g)} \ldots\ldots\ldots [5]$$

Where:

Me =normality of solution× ml of solution used

M =molarity of ferrous sulphate solution for blank titration

V1 =ml of ferrous sulphate solution required for blank

V2 =ml of ferrous sulphate solution required for sample

S =weight of air-dried sample in grammes

0.39 =$3\times10^{-3}\times100\times1.298$

Mcf =moisture correction factor

Soil pH

The Jenway pH/mV/ temperature meter was used to determine the pH of the soil in water (1:2.5) - soil: water solution). Twenty five (25) ml of distilled water was added to 10 grammes of the air-dried soil samples and shaken on a mechanical shaker, after which suspension was stirred gently. The

soil solution was allowed to equilibrate for 30 min. The pH meter was calibrated and the pH of the suspension determined.

Exchangeable Bases

Analyses of the exchangeable bases ($Ca^{2+,}$ $Mg^{2+,}$ K^{+} and Na^{+}) were done by the method described by Rowell (1994). Extraction was by the use of 100 ml ammonium acetate (NH_4OAc) solution of pH 7. The Ca^{2+} and Mg^{2+} in the extract were determined by titrimetry using Na_2 – EDTA procedure as described by Rowell (1994). With this procedure, aliquots of 25 ml of 1.0 *M* ammonium acetate extract was transferred into 250 ml conical flasks and diluted to 150 ml mark with distilled water. Fifteen (15) ml of buffer solution was added to each, followed by 10 drops each of KCN, NH_2OH, HCl, $K_4Fe(CN_6)$ and triethanolamine. After the additions, 20 minutes elapsed to ensure complete reactions. Ten (10) drops of Erichrome Black T indicator was added to each of the solutions and titrated with 0.005 *M* Na_2 – EDTA to a blue end point for both Ca^{2+} and Mg^{2+}. For exchangeable Ca^{2+} determination, aliquots of 25 ml of each extract were transferred into 250 ml and the procedure as stated above, were followed. Adjustment of solution pH at 12 was done by the addition of 10% NaOH. Five (5) drops of calgon indicator was added to each sample prior to titration and titration done with 0.005 *M* EDTA. Magnesium ion concentrations in samples were determined by subtracting titre values obtained for Ca^{2+} alone from Ca^{2+} and Mg^{2+} titre values. The K^{+} and Na^{+} concentrations were determined using a flame photometer. The formulae for calculating the various cations are shown below:

$$\text{Exc.}Ca^{2+}+Mg^{2+}=(4\times \text{T})/\text{Sample weight (g)} \quad \text{[6]}$$

Where:

Exc =exchangeable

T =titre value (millilitres) of 0.005M EDTA used

$Exc.Ca^{2+} = (4 \times T)/\text{Sample weight (g)}$…… [7]

$Exc.Mg^{2+}$ = Equation 6- Equation 7

In the determination of exchangeable acidity, the procedure described by Anderson and Ingram (1993) was followed. A solution of 25 ml of 1.0 *M* KCl was added to 10 g of the soil sample and the suspension stirred and filtered. The soil was then leached with 5 successive 25 ml aliquots of 1.0 *M* KCl. The phenolphthalein indicator was added to the aliquot and titrated with 0.1 *M* NaOH. The formular below was used to calculate the final exchangeable acidity:

$Exc.(Al^{3+}+H^{+}) = (2 \times T)/Sample\ weight\ (g)$……...[8]

Where:

T =titre value (millilitres) of 0.1M NaOH solution

The ECEC was calculated by summing exchangeable bases and exchangeable acidity (Anderson & Ingram, 1993).

Soil Physical Properties

The soil physical properties determined were bulk density, particle size distribution and field capacity (FC).

The bulk density of the soil was determined by the procedure of Anderson and Ingram for non- stony soils. Moist soil cores were oven- dried at 105°C and thereafter every 30 min until a constant weight was obtained. The dry bulk density was calculated from the formula:

$P_b = (W2-W1)/V$ ……..[9]

Where, P_b is the bulk density (g cm^{-3}), W_1 is the mass (g) of the metal cylinder, W_2 is the mass (g) of the metal cylinder plus the oven-dried soil and V is the volume (cm^3) of the metal cylinder.

Particle size distribution was determined using the Bouyoucos hydrometer method (Anderson & Ingram, 1993). Distilled water was added to the air-dried soil sample, followed by 20 ml of 30 % H_2O_2 to digest the organic matter. The mixture was then heated in a boiling water bath. Amyl alcohol was added to minimize frothing. Complete dispersion was achieved by adding 2 g of sodium hexa-metaphosphate. After the addition of distilled water, the suspension was shaken and transferred into a one-litre sedimentation cylinder. The suspension was shaken vigorously and both hydrometer and thermometer readings taken at 40 s and 5 hr.

The field capacity of the soil sample was determined following procedure described by Anderson and Ingram (1993). For the determination of gravimetric water content at field capacity, a vegetation-free area of 0.5 m × 2 m per plot was covered with a plastic sheet after the soil had drained for 3 days following deep saturation by applied water. Five 0–20 cm depth soil cores were bulked per plot and sub samples of the wet soil weighed. It was then oven-dried at 105 °C for 2 days and the soil reweighed. The gravimetric water content at field capacity (FC) was computed from the relationship:

$$FC(\%) = \{(W3 - W2)/(W3 - W1)\} \times 100 \quad \text{.....[10]}$$

Where:

W1 =mass (g) of the container

W2 =mass (g) of container and oven-dried soil

W3 =mass (g) of container and wet soil

Preliminary Poultry Manure Analysis

The poultry manure was analysed for pH, organic carbon (OC), total nitrogen (N), phosphorus (P), potassium (K), and moisture content.

Poultry Manure pH

The pH of the poultry manure was determined using pH meter (manure to water ratio of 1:2.5). The mixture was shaken on a mechanical shaker for 30 minutes after which the pH was measured.

Organic Carbon

Organic carbon was determined by the Walkley and Black (1934) method. One gram of poultry manure was wet oxidized with potassium dichromate ($K_2Cr_2O_7$) and concentrated sulphuric acid (H_2SO_4). The unreduced chromic acid was titrated against standard solution of ferrous sulphate, using diphenylamine as indicator. Percent organic carbon was calculated with the formula below:

%OC = {(me $K_2Cr_2O_7$- me FeSO4) × 0.003× 100 × (f)}/ $sample\ weight(\ g)$=

%OC= {M× ($V1 - V2$) × 0.39 × mcf} / S……[11]

Where:

me = normality of solution

M = molarity of ferrous sulphate solution for blank titration

V_1 = ml of ferrous solution required for sample

V_2 =ml of ferrous solution required for blank

S = weight of air-dried sample in gram

0.39 = $3\times10^{-3}\times100\times1.298$

mcf = moisture correction factor

Total Nitrogen in Manure and Biochar

Determination of total nitrogen in manure and biochar followed the kjeldahl method described by Hesse (1971) for plant analysis. A sample weighing 0.5 g each of the manure and biochar was digested with concentrated sulphuric acid (treatment replicated three times each). Twenty five mililitres (25 ml) each of the digests were distilled and collected over boric acid solution. The distillates were then titrated against 0.01 *M* HCl. The total nitrogen in manure and biochar was calculated by the formula shown below:

$$\%N = \{(S-B) \times T \times 14 \times 5 \times 100\} / 500 = 14(S-B) \times T \times M \quad [12]$$

Where:

S = volume of 0.01 *M* HCl used for sample titration

B = volume of 0.01 *M* HCl used for blank titration

T = molarity of HCl

M = moisture correction factor

14 = atomic weight of nitrogen

5 = sample dilution factor

500 = sample weight in mg

100 = factor for %

Determination of Total P and K in Manure and Biochar

The determination of total P and K in the manure was by mixed acid digestion procedure as described by Stewart et al. (1974). One-fifth grams (0.2 g) of air-dried poultry manure and biochar samples were weighed into 100 ml kjeldahl digestion tubes in three replicates, and 1 ml 60 % $HClO_4$, 5 ml of concentrated HNO_3 and 0.5 ml concentrated H_2SO_4 were added in that order. The contents were swirled gently and digested for 15 minutes in the kjeldahl

digester at 300 °C. The digests were allowed to cool to room temperature, diluted with distilled water and filtered through whatman No. 44 filter paper into 50 ml volumetric flasks, and made up to volume. The digest catered for the determination of K in the manure and not the biochar sample. P determination was done by the use of the Spectronic 20 Spectrophotometer at 880 nm after phosphomolybdate blue colour development. Potassium was determined by flame photometry.

Some Chemical and Physical Characteristics of Soil and its Amendments

The initial chemical and physical properties of the soil and the soil amendments are presented in Tables 1 to 3.

Table 1: Chemical Properties of Soil

Parameter	Units	Mean value ±Sd
pH		3.73±0.1
Total carbon	%	0.79±0.03
Total nitrogen	%	0.074±0.01
C:N ratio		10.76±1.6
Extractable P- Bray 1	Mg kg^{-1}	0.07±0.001
Exchangeable cations	$cmol_c\ kg^{-1}$	
Ca^{2+}	$cmol_c\ kg^{-1}$	0.95±0.001
Mg^{2+}	$cmol_c\ kg^{-1}$	0.43±0.001
K^{+}	$cmol_c\ kg^{-1}$	0.151±0.001
Na^{+}	$cmol_c\ kg^{-1}$	Nd
Total exchangeable bases	$cmol_c\ kg^{-1}$	1.531±0.02
Exchangeable acidity (Al^{3+} +H^{+})	$cmol_c\ kg^{-1}$	1.30±0.001
ECEC	$cmol_c\ kg^{-1}$	2.831±0.002

nd means not detectable

Table 2: Selected Physical Properties of Soil

Parameter	Value ±Sd	Texture
Particle size distribution		
Sand (%)	92.87±1.2	
Silt (%)	2.6±1.0	Sand
Clay (%)	4.53±1.2	
Bulk density (gcm^{-3})	1.3±0.01	

Table 3: Selected Chemical Properties of Soil Amendments

Material	pH	TN (%)	TC (%)	C:N	P (%)	K (%)	Ec (mS/cm)	Ash (%)
PM	7.5	1.29	17.55	13.59	0.68	0.65	ND	ND
Biochar(CC)	9.6	0.53	94.62	178.5	0.23	0.35	1.86	5.38
Biochar(OPP)	9.7	2.19	72.91	33.3	0.43	0.30	2.08	27.09

PM - poultry manure

CC – corn cob

OPP- oil palm press

EC- electrical conductivity

TC- total carbon

TN- total nitrogen

C:N- carbon nitrogen ratio

Statistical Analysis

The data were subjected to analysis of variance and Duncan's Multiple Range Tests for the separation of means using the GenSTAT 12.1(VSN International Ltd, 2009) and results presented pictorially using bar charts.

The next chapter presents the results on the performance assessment of the Lucia pyrolytic stove using locally available feedstocks.

CHAPTER FOUR

ASSESSMENT OF THE PERFORMANCE OF LUCIA PYROLYTIC (TOP LIT-UP DRAFT) (TLUD) STOVE USING LOCALLY AVAILABLE FEEDSTOCKS

Introduction

Traditional way of providing energy for home using the swish type of stoves is fraught with a lot of inconveniences. Notably among these is the poor burning leading to the emission of high levels of particulate matter (PM), oxides of nitrogen (NO_x) as well as carbon dioxide (CO_2) which have several health implications for our women and children (UNDP & WHO, 2009). This defect of the traditional swish stove is responsible for the inefficiency and the high fuel wood consumption.

The forest cover of Sub-Saharan Africa (SSA) is continuously declining. This is due to deforestation through man's quest for energy and increased land use for farming activities. The forest cover of SSA has declined from 4.5 million ha yr^{-1} in 1990-2000 to 4.4 million ha yr^{-1} in 2000-2005, representing an annual rate of 0.64 % and 0.62 % for the periods 1990-2000 and 2000-2005, respectively (FAO, 2005). In Ghana (2 %) decline in forest cover, between the same periods, was recorded, compared to the Africa average of 0.02 %. The (2 %) figure recorded indicates that Ghana still has to take more serious measures to fight against deforestation. Owing to the relatively high rate of deforestation, Ghana's capacity to continuously supply

fuel wood for the rural communities for their daily energy use cannot be guaranteed in the foreseeable future. Moreover, the forest may no longer continue to play its vital role in ecological sustainability if alternative sources of energy are not provided to people living in the rural areas. The inefficiency of swish stoves used by mostly rural dwellers in developing countries does not only endanger the users health but also endangers the environment through the emissions of some important green house gases such as CO and CO_2, which are mostly implicated in climate change through global warming.

New technologies have been developed for the provision of energy to help curb deforestation. Notable among these technologies is the use of liquefied petroleum gas (LPG). The Government of Ghana has since the early 1990s been promoting the use of LPG, primarily through the National LPG Campaign. The main objective of this campaign was to introduce the Ghanaian public to an alternative cooking fuel, other than wood fuel and electricity. While this drive has yielded significant results in the urban areas, the rural market remains underserved (UNDP, 2004). The use of LPG is plagued with some other challenges: the initial cost of LPG compared to wood fuels, and the poor LPG distribution networks in the country (Amissah-Arthur & Amonoo, 2004). Again, the inability of the Tema oil refinery to catalytically crack and produce the needed quantites of fuel from crude oil to meet its growing demand has led to even urban dwellers resorting to the use of charcoal. These challenges thwart the efforts of environmentalists, governments and other stakeholders who are involved in the fight against deforestation in general and global warming, in particular.

A lot of different kinds of improved biomass stoves have been deployed in different countries with the aim of overcoming the two major drawbacks of traditional stoves, which are low efficiency and indoor air pollution (Bhattacharya et al., 2002). These stoves mostly use crop residues, thereby easing the pressure on forests for fuel wood, but the sustainability of these stoves would greatly depend on their efficiency and versatility to varying sources of biomass or feedstocks.

Therefore, for the adoption and acceptability of the Lucia pyrolytic biomass stove by users, there was the need to assess the efficiency of this stove. The study was undertaken to answer the following questions:

1. Which feedstock brings water to boiling at a faster time?
2. What is the burning duration time of the two feedstocks tested?
3. What is the pH of the residual water after quenching biochars from these two feedstocks ?
4. What are the flame characteristics of these two feedstocks ?

Materials and Methods

The study was conducted at the Technology Village of the School of Agriculture of the University of Cape Coast of the Central Region of Ghana. The study stretched over a period of six months from late November, 2010 to mid June, 2011.

Experimental Procedure

Stove

The stove used in this study, the Lucia biomass pyrolytic stove (TLUD) was developed by Worldstove International in Italy.

The stove is made of steel with two cylinders, an outer and an inner cylinder. The inner cylinder has diameter of 10 cm and that of the outer cylinder is 15 cm. The internal cylinder has a height of 32 cm whiles that of the external cylinder is 33 cm. The stove comes with a lid which has an opening in the centre just enough to cover the outer cylinder opening at the top but leaving the opening for the inner cylinder for combustion to take place. The stove weighs approximately 2.42-2.44 kg without the lid. The special design features include four special distinct perforations. The first consists of circular perforations of between 10-12, evenly spaced with one situated at the centre, all at the bottom of the inner cylinder. The next category of perforations comes with slanted vanes perforated at the bottom of the outer cylinder. The third category of perforations is just made half way down the inner cylinder and is smaller than those made at the bottom of the stove. The final perforations are three tiny ones made half way on the outside of the outer cylinder. To ensure complete pyrolysis of feedstock by the stove, a grid measuring 10 cm in diameter and 7.5 cm in height is made to fit the inner cylinder. The stove uses both pellets and non pellet biomass as fuel. Plate 1 shows photograph of the Lucia biomass pyrolytic stove.

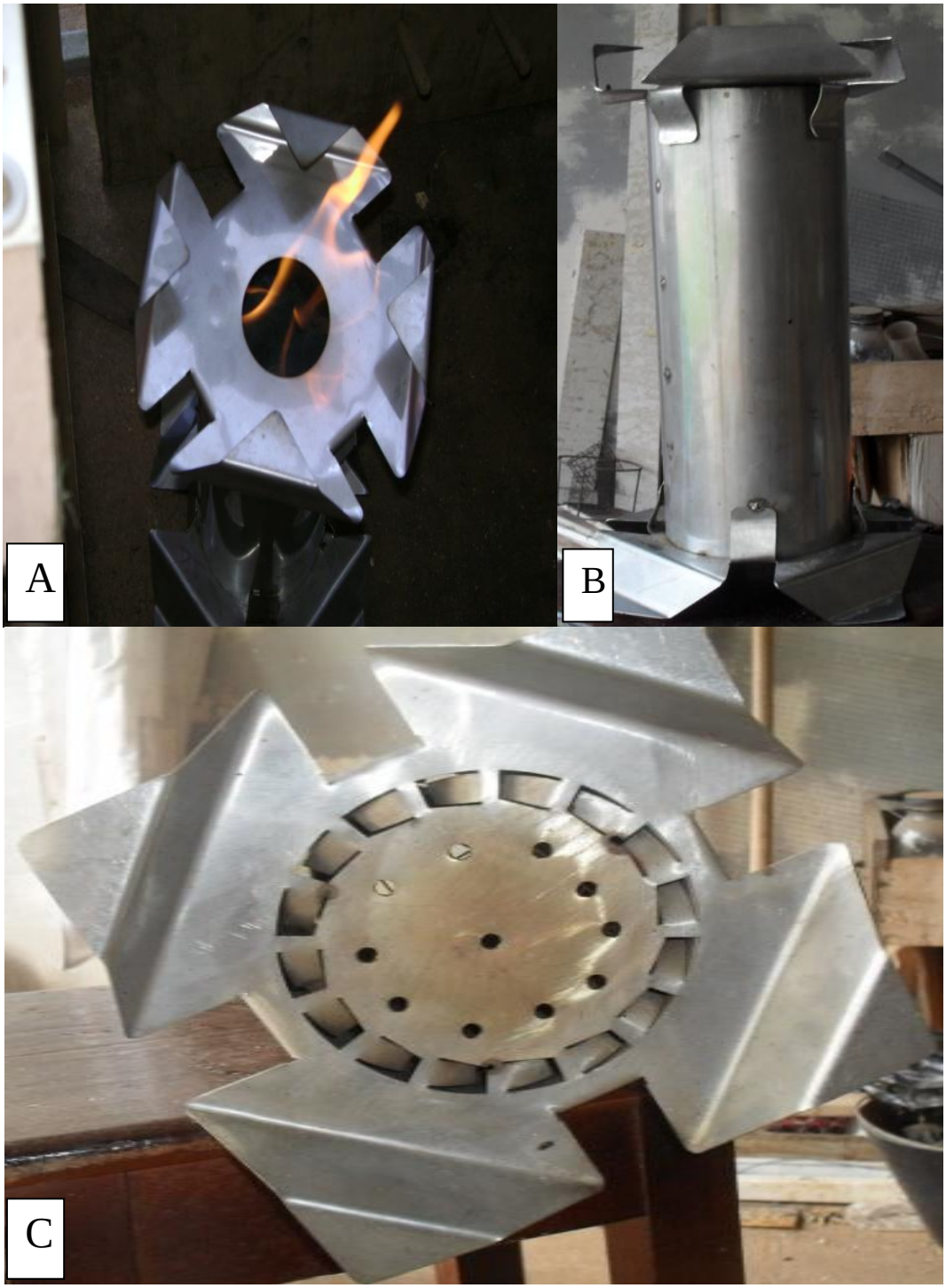

Plate 1. Features of the Lucia biomass stove: (A) stove in use; (B) side view of stove; and (C) stove bottom showing primary air inlet

Fuel

Feedstocks, unpelletized, from both oil palm press (OPP) and corn cob (CC) were used as fuel in this study. The OPP was obtained from Afiaso, an oil palm farming community in the Twifo-Heman-Lower Denkyira District of the Central Region, after the extraction of palm oil through manual and mechanical extraction and the CC obtained from the farms of the School of Agriculture, University of Cape Coast, Central Region, Ghana. The fuel materials were dried to reach 10 % moisture content before being used. The fuels were used in their unpelletized forms. The OPP was used after loosening and separating most palm kernel nuts. The CC was used after it had been crushed into pieces of about a centimeter long. The quantity of each fuel used in the study was 240 g. Plate 2 shows feedstock used in the study.

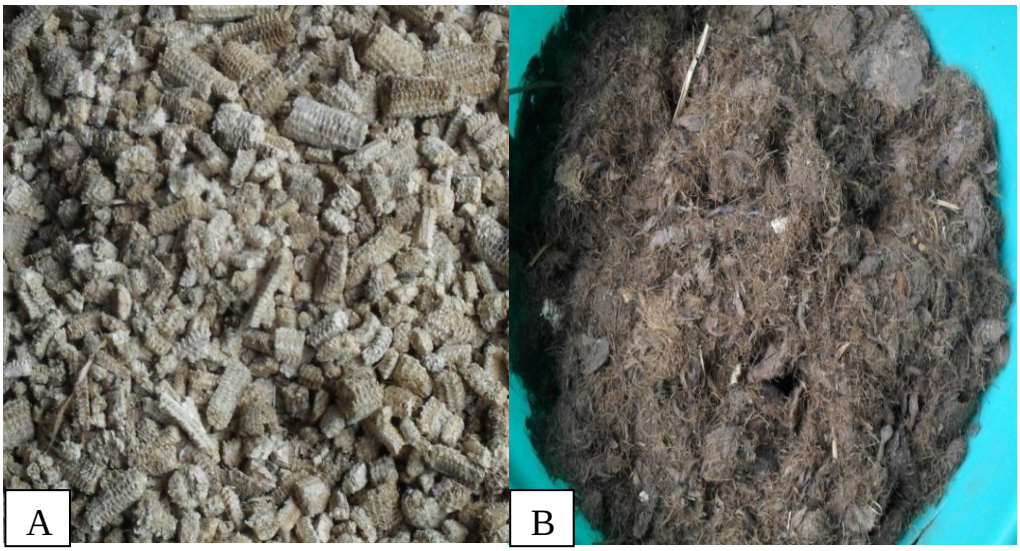

Plate 2. Unpelletized feedstocks used in the study: (A) corn cob (B) oil palm press

Fire Starter

Lighting of the flames for each test was aided by the use of a starter which is a saw dust-wax mixture in the ratio of 1: 2 (50 g of sawdust and 100 g of wax). The wax was obtained from molten candle. This starter ratio

enabled the production of starters that are easily pulverized with the fingers to allow for spreading unto feedstocks.

Feedstocks Loading

Measuring of the weight of feedstock loaded into the inner cylinders was achieved by initially weighing the empty cylinders, followed by the loading to the brim of the inner cylinders but leaving a space of 6 cm to the brim of the inner cylinder. Lighting of the stoves is achieved by top lighting after copiously spreading of 10 to 20 g of the starter and lighting with a safety match.

Stove and Feedstock Assessment

The parameters measured were duration of burning each type of feedstock, which were corncobs (CC) and oil palm press (OPP). The other parameters measured were biomass consumption rate, biochar yield, boiling duration test and pH of the residual water (pH of quenched water).

Burning Duration Test

For this test 240 g of corncobs were weighed into 2 randomly selected stoves with the grids and starter applied to aid in the lighting of the fire. Timing began after a minute of starting of fire and this was done to ensure that the starter was not mistaken to be part of the feedstock. When burning stopped, the time was recorded and the difference gave the burning duration. This process was repeated for the 2 stoves 3 times, giving a total of 6 burnings.

Biomass Consumption Rate

In this test, same stove sampling procedure for burning duration was adopted and same feedstock weight also considered. Biomass consumption

rate was arrived at by dividing the amount of feedstock consumed by the burning duration of each test. Results recorded were subjected to analysis. This method was made possible since there was complete burning in each test due to the introduction of the grids.

Biochar Yield

The rate of turnout of each type of biochar was done by oven drying the burnt biochar which had been quenched with a known volume of tap water, which were 0.9 litres for OPP and 1.2 litres for CC. These samples were duplicated to ensure reliability of dry mass biochar produced by each type of feedstock. The oven dried masses were then subjected to analysis and the results recorded.

Boiling Duration

For this test, three litres of tap water was measured using a measuring cylinder and emptied into an aluminium moulded cooking pot. Each type of feedstock was weighed into randomly selected stoves; the fire started and the time noted as described in the first test. The time taken for boiling to start was identified by the rapid escape of steam vapour from the uncovered portions of the top of the rim of the pot. See figure 4.2 for bar graph of the results obtained from these tests.

pH of Residual Water (Quenching Water pH)

Due to the differences in the nature of biochar produced, different quantities of water were used to quench the charred biomass. For corncobs, the amount used was 1.2 litres whiles for the oil palm press, it was 0.9 litres. This was to ensure that there was some amount of water left to be filtered for pH measurements.

Flames Characteristics

In this test, the period of appearance of blue flame over red or yellow flame was assessed. How often do the flames go off and the smoking behaviour of each type of biomass feedstock as well as the amount of soot and tar that covered the bottom part of the cooking pot (coverage by percentage). The results of this test are presented in Table 4.

Results and Discussions

The findings made on the feedstock assessment with Lucia stove are presented in Figures 1 to 5.

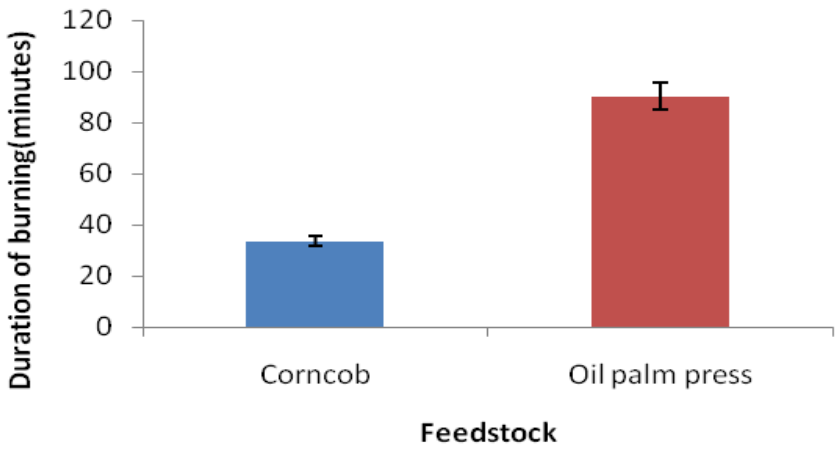

Figure 1. The burning duration of corn cob and oil palm press. Error bars represent S.E at $P < 0.05$.

The time it took 240 g each of CC and OPP to be completely pyrolysed was investigated. The study showed that CC feedstocks was pyrolysed com pletetly in 33.7 ± 1.92 minutes whiles the OPP samples were completely pyrolysed in 90.2 ± 5.23 minutes. Thus, the recorded burning durations between the CC and OPP significantly ($P < 0.05$) varied (Figure 1). The comparatively longer duration of the OPP feedstock could be attributed to the

differences in densities, with the OPP being denser than the CC feedstock. This phenomenon has been explained in detail by Christa (2011) that fuel properties have a significant influence on the rate at which fuel burns. She indicated that high density fuels have a higher energy values than low density-fuels. The differences in burning duration observed between the CC and the OPP can also be attributed to the fluffy nature of the OPP fuel which impedes primary air flow compared to the compacted nature of the CC. Fluffy feedstocks can reduce char gas formation and consequently its burn rate. Further, the longer burning duration of the OPP could be attributable to the OPP having significant quantities of oil on it, as observed during feedstock testing, thereby prolonging its burning period.

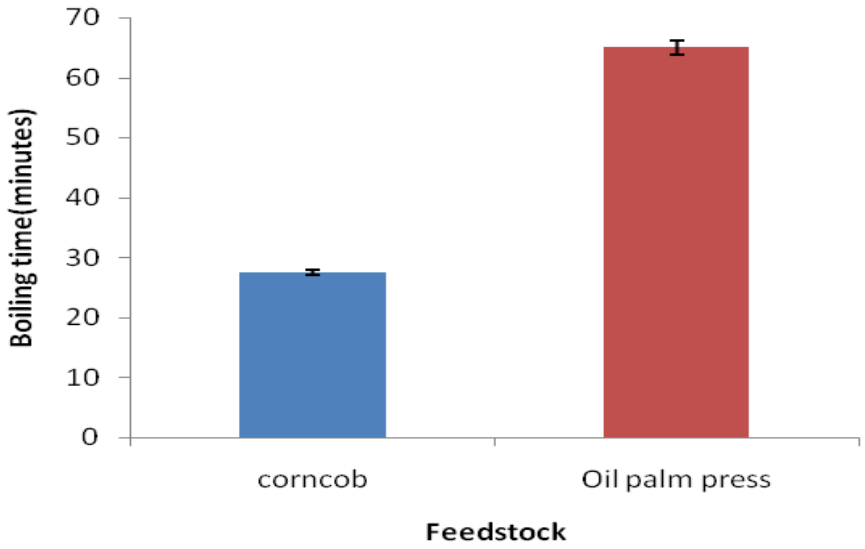

Figure 2. Influence of corn cob and oil palm press on boiling duration of water. Error bars represent S.E at $P < 0.05$.

The study also investigated the boiling time, i.e; the period within which it took three litres of tap water at room temperature in an aluminium molded cooking pot to start boiling after it had been placed on the stove fed to each type of feedstock. The study revealed that it took 27.5 minutes for the water to boil on the stove fed with CC compared to that fed with OPP, which

required 65 minutes (Figure 2). This difference observed, from the above data could be explained by the significant differences in consumption rate (burn rate) between these two feedstocks (Figure 5). Figure 5 shows that, the burn rate of CC 7.3 g $min^{-1}$was significantly ($P < 0.05$) higher than that of OPP, 2.7 g min^{-1}. The burn rate is a measure of the fire power of each feedstock and the higher the burn rate, the higher the fire power, hence, the observation made in Figure. 2. The difference observed could also be due to differences in primary air impedance which was higher in OPP than in CC feedstocks. Greater compression is required to fit OPP feedstocks into a given volume of the chamber compared to CC feedstocks. As a result, primary air through the base of OPP is more impeded than in CC feedstock, thus creating greater wood-gas generation and higher fire power in CC than in OPP feedstock.

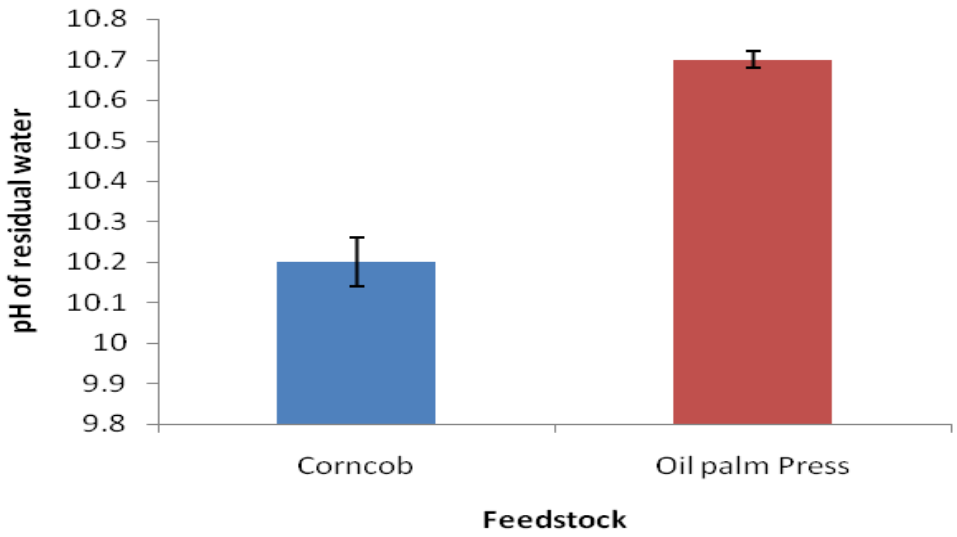

Figure 3. Influence of corn cob and oil palm press on pH of residual water. Error bars represent S.E at $P < 0.05$.

The pH of residual water from biochars produced from each feedstock revealed a significant difference ($P < 0.05$) between the CC and the OPP. The corn cob had an average pH of 10.2 ± 0.06 whiles that of the OPP was 10.7 ± 0.02. This indicates a pH unit difference of 0.5 implying that the OPP

produced biochar that was more alkaline than that of the corn cob. The difference in pH between the two feedstocks could be attributed to higher levels of ashes in OPP than in CC (Table 3). This implies that the OPP could be more effective in lowering soil acidity than CC.

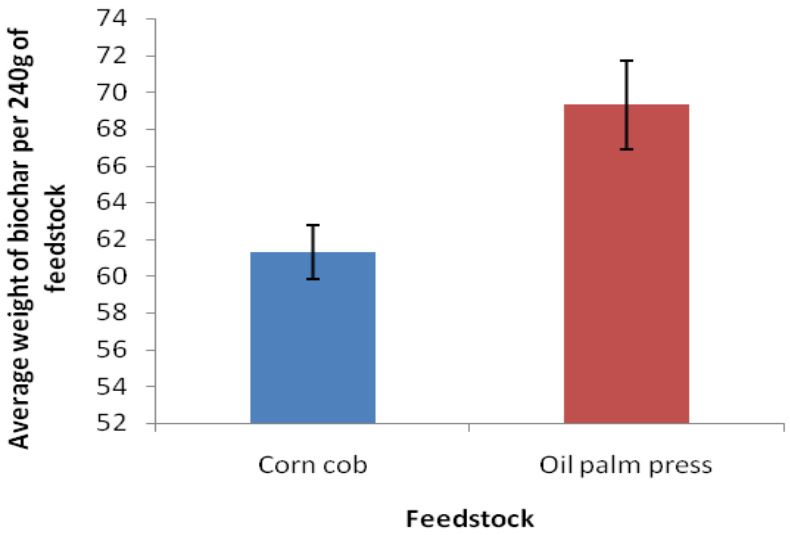

Figure 4. Mean dry weight of biochar obtained from corn cob and oil palm press feedstocks. Error bars represent S.E at $P < 0.05$.

Studies were conducted into the effect of introduction of the grid on biochar turnout rate of each feedstock type. It was revealed that the average weight of biochar produced from the OPP was higher (69.3 ± 2.4 g) than that of the CC (61.3 ± 1.5 g) on oven-dry weight basis (Figure 4). This difference could be attributable to the differences in their burn rate, 7.3 g min^{-1} for the CC and 2.7 g min^{-1} for the OPP (Figure 5), respectively, indicating that the CC burns more than 2.7 times faster than that of the OPP.

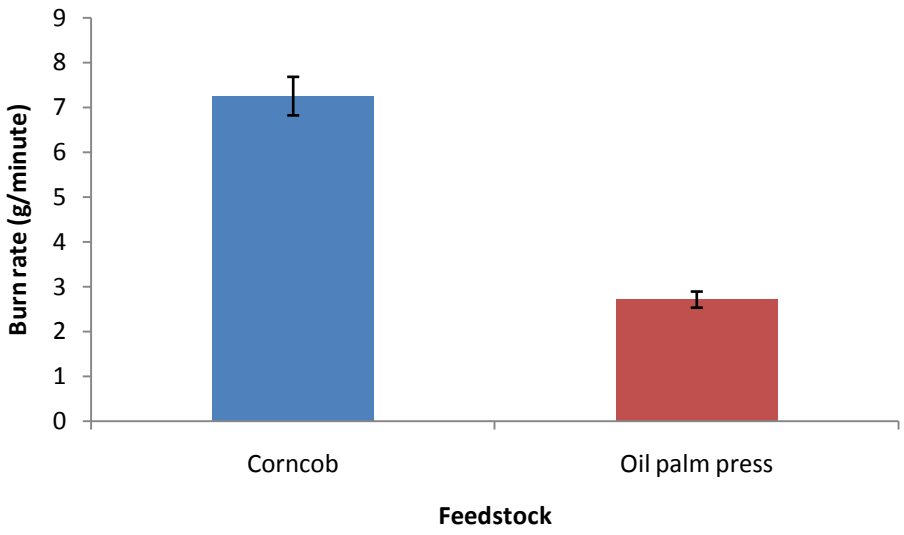

Figure 5. Mean burn rate of corn cob and oil palm press. Error bars represent S.E at $P < 0.05$.

Results on the burn rate from the two feedstocks indicated that the burn rate of the CC was higher (7.3 g min^{-1}) than that of the OPP (2.7 g min^{-1}). This difference could be as a result of differences in their densities and structural composition (data not shown). The CC has lower density than the OPP hence pyrolyses faster than that of the OPP. The structural composition also contributes to the density of the feedstock being investigated which has a direct relationship on the burn rate. In terms of composition, cellulose component is greater than lignin in CC while OPP has more lignin than cellulose. The greater the content of cellulose, the less dense the material and the faster it undergoes pyrolysis.

Flame Characteristics

Table 4: A Comparison of Flame Characteristics of Corn cob and Oil Palm Press Feedstocks

	Feedstock					
	Corn cob			Oil palm press		
Parameter	**Time(mins)**	**Frequency**	**%**	**Time(mins)**	**Frequency**	**%**
Blue flame occurrence	5	4	66.7	15–20	4	66.7
	10	2	33.3	30–50	2	33.3
Flame peaking	8–10	4	66.7	50–55	4	66.7
	10–15	2	33.3	60+	2	33.3
Flame	30	6	100	70–85	6	100
Soot alone (%)*	10	1	16.7	20	1	16.7
Soot and tar (%)*	100	5	83.3	70–80	5	83.3
Tar occurrence (%)*	0	0	0	0	0	0
Intermittent smoking	10–12	3	50	80–90	2	33.3
	13–15	2	33.3	0	4	66.7
	0	1	16.7			

(%)* refers to area of coverage of the bottom part of the aluminium molded cooking pot.

Flame peaking refers to the time at which flames are seen to be burning vigorously.

Flame falling refers to the period in which flames are seen to be reducing their burning vigour.

Intermittent smoking-describes the period within which there is the observed erratic smoking which usually last for between 2 to 5 minutes.

Table 4 indicates the flame characteristics of CC and OPP which were observed when tested on the Lucia biomass pyrolytic stoves. On the occurrence of blue flame, it was observed that the CC generally tended to have

a shorter time of either 5 minutes (66.7 %) or 10 minutes (33.3 %), whiles that of OPP was either between 15-20 minutes (66.7 %) or 30-50 minutes (33.3 %). The time of occurrence of the blue flame might be dependent on density, a property which is influenced by the structural nature of the two feedstocks in which the CC tended to be less dense compared to the OPP (data not presented). Again, blue flame occurrence in biomass burning is a function of burning of carbon monoxide (CO). Therefore, the early occurrence of the blue flame in CC is an indication of release and subsequent burning of CO and also an indication of period of less smoking occurrence at the bottom of the test pot

On flame peaking, it was realized that the CC started either between 8-10 minutes and this represented 66.7 % or between 10-15 minutes representing 33.3 %. The OPP flame started peaking either between 50-55 minutes representing 66.7 % or 60 minutes and above which represented 33.3 %. Flame peaking refers to the period of vigorous burning of feedstocks leading to increases in the height of flame at the top of the stove. The early peaking of flames in the CC than in the OPP could be attributed to the burn rate, which was 7.2 g min^{-1} for CC and 2.7 g min^{-1} for the OPP (Figure 5), and the higher the burn rate the earlier the occurrence of the blue flames, which also tended to be temperature dependent. That is the higher the burn rate, the higher the temperature and the bluer the flame.

The results on the period at which the flame began to fall recorded 30 minutes for CC which represented 100 % whiles that of the OPP recorded a time between 70-85 minutes representing 100 %. This means that flame fell early in CC than in OPP. The percentage means that no other time of flame falling was observed apart from those presented in the table. The flame falling

period is an indication of the decline or the nearness to completion of the pyrolysis process which depends on the availability of feedstocks. From the burning duration test, it was observed that averagely, it took the CC 33.7 ± 1.92 minutes whereas that of the OPP was 90.2 ± 5.23 minutes for complete pyrolysis of the same quantities (240 g) of feedstocks. These values therefore confirm why it took a shorter time for flames to fall in CC than in OPP. However, the wide range of flame falling time observed in OPP could be as a result of heterogeneous nature of OPP since the material used was obtained from sources that predominantly used manual processes which accounts for compositional variations of the fiber, and particularly the oil content.

In measuring the flame characteristics, the presence or absence of soot, tar and the extent of their coverage on the surface of the bottom part of the aluminum molded cooking pot used in this experiment, were noted. The results obtained indicated that, with CC, one out of the six tests representing 16.7 % had soot alone covering about 10 % of the pot surface, whiles five of the tests representing 83.3 % had 100 % soot and tar covering the surface of the pot. However, the test did not record tar alone covering the pot surface when using both feedstocks. On the other hand, OPP also recorded out of the six tests, representing 16.7 % having soot alone covering about 20 % of the pot surface. Five out of the six tests representing 83.3 % had both soot and tar covering about 70-80 % of the pot surface. There was no tar alone coverage (0 %) recorded in the tests using OPP feedstocks.

On smoking trend of the feedstocks used, the characteristic observed and recorded was intermittent smoking, which is the time when smoking is seen to interfere in the burning process since it hinders the proper burning of

the feedstocks. The tests results indicated that for CC feedstocks, intermittent smoking frequencies occurred between the times of 10-12 minutes representing 50 % of the tests. The time periods of between 13-15 minutes were also noted, representing 33.3 % of the tests. However, there was one out of the six tests representing 16.7 % which did not experience any intermittent smoking. Regarding OPP feedstocks, results showed that intermittent smoking frequencies was observed between the time periods of 80-90 minutes, representing 33.3 %, whiles four out of the six tests representing 66.7 % did not show any smoking interference. The high number of intermittent smoking frequencies totaling 83.3 % as seen in the CC could be attributed to unequal surface contact between the CC and the heat front on the inner metal surfaces leading to smoking which interferes in the burning. Contrary to the CC, the OPP was generally observed to have less intermittent smoking (66.7 %) and this could be as a result of better contact between feedstock and the heat front on the inner metal surface. However, the remaining 33.3 % smoking observed could be as a result of burning of some feedstock that fell through the mesh of the grid to the bottom of the stove causing smoking. This is confirmed by the time the smoking was observed (80-90 minutes), which is close to the average burning duration for OPP feedstock (90.2 minutes).

Summary and Conclusions

Water boiled faster on the Lucia stove fed with CC than with OPP.

The OPP burnt longer than the CC, implying that the OPP could be a better feedstock for cooking dishes that demand longer periods.

The pH of the residual water after quenching biochars from these two feedstocks recorded an average pH of 10.2 ± 0.06 for CC whiles that of OPP

was 10.7 ± 0.02. This implies that the residual water from oil palm press biochar would reduce soil acidity further than that of corn cob.

Heat supply from CC was faster than from OPP. Flames generally peaked earlier and fell faster in CC than in OPP., and this ensures faster heating using CC than OPP. Flames fell generally faster in CC than as observed in OPP. It means for longer cooking periods, OPP could be opted for as a feedstock.

There was less smoking coverage on pot surfaces when OPP was utilized as a source of fuel in cooking with this stove.

It is concluded that the OPP could be a better feedstock for cooking dishes that demand longer periods using the Lucia stove. Although the OPP has better burning duration than the CC biomass, it was not chosen for the pot experiment in the next chapter due to fear of heavy water and wind transport susceptibility of its biochar as a result of its fineness.

CHAPTER FIVE

EFFECTS OF CORN COB BIOCHAR APPLICATIONS ON THE GROWTH AND YIELD OF LETTUCE (*LACTUCA SATIVA* L.)

Introduction

Ghana is faced with the problem of increasing food production to meet its ever increasing population. Oxisols are a group of soils characterized by high acidity, low organic matter content, low activity clay minerals as well as low levels of the major macronutrients – nitrogen (N), phosphorus (P) and potassium (K). There is also the problem of high micro nutrient toxicities as a result of the high acidity of this soil and the effect could be detrimental to both plants and other soil living organisms.

A common treatment to reduce the solubility of Al, and the other heavy metals in soils is to increase the soil pH that is mostly achieved through liming (Ahmad & Tan, 1982; Hakim et al., 1989; Haby, 2002). The ability of liming to increase soil pH, decrease Al and other heavy metal solubility, and increase crop yield is widely known (Shamshuddin & Auxtero, 1991; Haby, 2002; Kaderi, 2004; Brown et al., 2008). In Ghana, however, liming as a practice to remediate these types of anomalies in such soils is not well known. Furthermore, Thomas et al. (2003) found out that liming on an acid sulphate soil only treated the symptoms and not the cause of the symptoms, indicating that the effect of liming is temporal and has to be repeated (Shamsuddin et al.,

1998). This makes liming very expensive and uneconomical for smallholder farmers to adopt.

The other treatment suggested for remediating such nutrient deprived soil is the application of organic matter (Kaderi, 2004; Shamsuddin et al., 2004). With these, negative charges are provided by the organic matter through the carboxyl compounds which minimize the toxicities of these heavy metals by decreasing their solubility in the soil solutions. The organic matter effects on properties of acidic soils, such as increasing soil pH and CEC, and decreasing heavy metal toxicity, have been reported comprehensively (Hesse, 1982; El Sharkawi et al., 2006), supplying nutrients to crops, supporting rapid nutrient cycling through microbial biomass, and helping to retain applied mineral fertilizers (Goyal et al., 1999; Trujillo, 2002). Again, the benefits of organic amendments, are however, often short-lived, especially in the tropics, since decomposition rates are high (Jenkinson & Ayanaba, 1977) and the added organic matter is usually mineralized to CO_2 within only a few cropping seasons (Bol et al., 2000). Organic amendments therefore need to be repeated yearly to sustain soil productivity.

The management of black carbon (C) – increasingly referred to as bio-char – may overcome some of these limitations and provide additional soil management options. Interest in application of biomass-derived black carbon was prompted by studies of soils found in the Amazon Basin, referred to as Terra Preta de Indio (Lehmann et al., 2003b). These soils even maintained their high fertility thousands of years after abandonment by the indigenous people, contrasting distinctly with the low fertility of the adjacent acid upland soils (Lehmann et al., 2003b).

The reasons for this soil's high fertility are multiple, but the source of the large amounts of organic matter and their high nutrient retention has been attributed to the extraordinarily high proportions of black carbon (Glaser et al., 2001).

Due to the recalcitrance of C –organic in this black carbon material, there has been much interest, recently, in their use as soil amendments to improve and maintain soil fertility and to increase soil carbon sequestration (Glaser et al., 2002a, 2002b; Lehmann et al., 2003). The latter can be attributed to the relative stable nature and, hence, long turn over time of biochars in soil is of particular importance to the solution of climate change (Lehmann et al., 2006). Even though, there have been some objections to the use of biochars as soil amendments (Ernsting & Smolker, 2009; Senjen, 2009), quiet a number of experimental results have indicated positive effects of biochars additions on soil properties (Lehmann et al., 2003; Liang et al., 2006; Chan et al., 2007) and increased crop yield (Yamato et al., 2006; Chan et al., 2008). Chan et al. (2007) found that applications of biochar improved some physical soil properties, such as increased soil aggregation, water holding capacity, and decreased soil strength. Again, Chan et al. (2007) showed that biochars additions could increase soil organic carbon, soil pH, and CEC. Yamato et al. (2006) utilized *Acacia magnum* biochar and it increased the soil pH, Ca, base saturation, and CEC, and decreased Al saturation. Novak et al. (2009) showed that the application of biochar in the acidic coastal soil of the Southern US could increase soil pH, soil organic matter, Mn, and Ca and decreased Sulphur (S) and Zn. On this sandy soil, the biochars applied did not significantly increase the CEC of the soil. Rondon et al. (2007) reported of

increases in soil biological activity upon biochar additions to soil cultivated with *Phaseolus vulgaris* L. for nitrogen fixation and for earthworm and microbial biomass (Chan et al., 2008).

For increases in crop yield, biochars applications have been reported for crops such as cowpea (Yamato et al., 2006), maize (Yamato et al., 2006; Rodriguez et al., 2009), soybean (Tagoe et al., 2008) and radish (Chan et al., 2008).

The objective of this work was to study the characteristics of biochars produced from corn cob and its effects on the growth and yield of lettuce (*Lactuca sativa* L).

Materials and Methods

Production and characterization of corn cob biochar

The feedstock, unpelletized, from corn cob (CC) was used as fuel in this study. The CC was obtained from the farm of the School of Agriculture, University of Cape Coast, Central Region, Ghana. The feedstock was pyrolysed using the Lucia pyrolytic stove made of a stainless steel of 35 cm long with inner cylinder diameter of 10 cm. Pyrolysis was achieved by loading the inner burning chamber (cylinder) with 240 g of biomass. Ignition was achieved by spreading a reasonable quantities of the starter (mixture of bees wax and saw dust) unto each biomass and top lit with a safety match and the lid placed on the stove after 1–2 minutes of burning of starter. Recorded temperature of pyrolysis was 300 ℃. Photographs of the stove and its components are presented in chapter four Plate 1.

The biochar was characterized for pH, total carbon, total nitrogen and total phosphorus as was described in chapter three pages 23 to 27. The Total

Dissolved Solids (TDS) - electrical conductivity was analysed using the conductivity meter following the procedure of McLaughlin (2010).

Soil

The soil used in this study was collected from the Agricultural Research Farm of the Ellembele District Agricultural Development Unit near Aiyinasi, in the Western Region of Ghana. The soil was an Oxisol (WRB, 2006), sandy with pH averaging 3.73 (WRB, 2006). It is a typical agricultural soil of the Western region of Ghana and the site has a long history of cropping. The A horizon has low soil organic carbon content and is sandy with pH of 3.7. A composite sample was collected from the 0–20 cm layer, brought back to the laboratory, air-dried, crushed and sieved through a 2 mm sieve.

Experimental Setup

A six (6) week incubation study was conducted with the above described soil with lettuce (*Lactuca sativa*.L).

The experimental design used was the completely randomized design with four replications. This gave a treatment total of 24. Biochar was incorporated into soil on weight per weight basis as follows:

(Ao) =Control (soil only).

(A1)= 1% (26 t ha^{-1} equivalent) weight per weight basis.

(A2) = 2% (52 t ha^{-1} equivalent) weight per weight basis.

(A3)= 3% (78 t ha^{-1} equivalent) weight per weight basis.

(A4)= 4% (104 t ha^{-1} equivalent) weight per weight basis.

(A5)= 5% (130 t ha^{-1} equivalent) weight per weight basis.

Air-dried soil and biochar amendments mixtures (1 kg equivalent) were packed into plastic cylindrical pots (11.5 cm in diameter and 11 cm tall)

to achieve a bulk density of 1.3 Mg m^{-3}. A 1 % biochar to soil mixture means 10 g of biochar to 1000 g of soil. Each seedling of lettuce (*Lactuca sativa*.L), 2 weeks old, was transplanted into each pot. The pots were placed individually in shallow trays and regularly watered to maintain water content at approximately 60 % of field capacity using distilled water, throughout the 6 weeks duration of the experiment. The plants were harvested at the 6th week after transplanting (WAT), and fresh and total dry matter determined for each treatment. Before the total dry matter determinations were done, four plants from each treatment were assessed for growth by measuring the longest leaf of each plant from the node of the stem and the average taken for that particular treatment.

Soil and Plant Growth Analyses

At the end of the incubation period (6 weeks), the lettuce plants were harvested by removing them from the individual pots. The plants were washed with distilled water, oven-dried at 70 °C to constant weight before weighing to determine the total dry matter production. After harvest, the soil from each pot was air-dried, mixed thoroughly, and crushed gently to pass through a 2 mm sieve. The <2-mm samples were then analyzed for pH, total organic C, total N, Bray 1–extractable P, and exchangeable bases (Ca^{2+}, Mg^{2+} and K^{+}) determined according to method described by Rowell (1994). Exchangeable acidity (Al + H) was determined by the procedures described by Anderson and Ingram (1993). The pH was measured in 1: 2.5 soil to water ratio, total organic carbon determined by the wet oxidation method, Walkley and Black (1934). Total nitrogen determined by acid digestion and total nitrogen was analyzed by the micro-kjeldahl method, available P was extracted by using Bray No.1,

and P concentration determined by using the spectrophotometer (Spectronic 20) at 880 nm.

The plants were harvested at 6 weeks after transplanting (WAT), fresh and total dry matter (biomass) as well as leaf number at maturity were determined. Before the total dry matter determination was done, plants from treatments were measured for growth by measuring the longest leaf of each plant from the node of the stem and the average taken for that particular treatment. Total dry matter was determined by oven drying the biomass at 70 °C to a constant weight

Statistical Analyses

All data were subjected to analysis of variance using GENSTAT 12.1(2009).The treatment means were compared using least significant differences for the main effects of biochar.

Results and Discussion

Height of Lettuce at Harvest as Affected by Biochar Treatments

The absolute heights of lettuce plants taken at 6 weeks after transplanting (WAT) were significantly different ($P < 0.05$) (Figure 6).

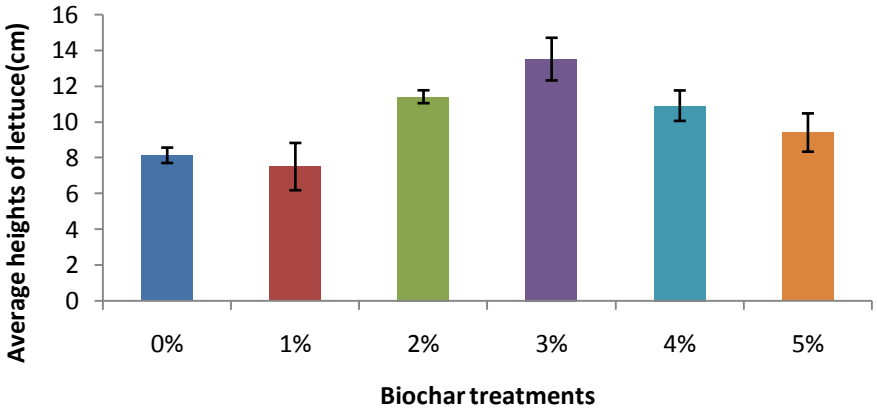

Figure 6. Average heights of lettuce as affected by biochar treatments at 6 WAT. Error bars represent S.E at $P < 0.05$.

Amongst the treatments, A3 (3 % biochar) had the highest effect on increasing plant height (13.5 ± 1.19 cm); representing a 1.7 times increase in height compared to the control, whilst A1 had the least plant height (7.5 ± 1.32 cm); indicating a 0.92 times reduction in height compared to the control. The control and A1 were not significantly different from each other.

Generally, plant height increased with increasing rate of biochar applied up to 3 % (w/w) after which height reduction occurred. The appication of 1 % (w/w) biochar had no significant effect on plant height but 2 % (w/w) and 3 % (w/w) rates of the biochar significantly increased the plant height. However, treatments A4 and A5, representing biochar rates of 4 % and 5 % recorded height declines, compared to the 3 % rate, with 5 % rate showing no significant effect on heights of lettuce compared to the control. The increases in heights of lettuce observed in treatments A1 to A3 could be attributed to the increases in the levels of available P observed in the post harvest soil analysed (Chapter Seven,Table 5). The increases in pepper (*Capsicum annum* L.) and tomato (*Lycopersicum esculentum* Mill) height with biochar has been reported by Graber et al. (2010). In the previous study, the increases in plant height was attributed to one of two mechanisms of "charcoal effect" which are: (i) the stimulated shift in microbial populations towards plant growth promoting rhizobacteria or fungi, due to either physical or chemical attributes of the biochar or (ii) low concentrations of chemicals in biochar stimulated a plant immune response inducing more aggressive growth (Graber et al., 2010). Conversely, the negative effects of biochar applications on the height of lettuce as observed in treatments A4 and A5 could be attributed to increased N deficiencies caused by biochar, which has high C:N ratios (Asai et al.,

2009). Similar observations were made by Kammann et al. (2011). They observed plant height increases with biochar applications of 0 and 100 t ha^{-1} . They further reported that, higher doses of 200 t ha^{-1} of biochar lead to height decreases of *Chenopodium quinoa* Willd. This, they ascribed to N deficiencies at higher biochar applications resulting from N immobilization. Furthermore, treatments A4 and A5 impacted negatively on the growth (heights) of the plants and this could be as a result of water stress caused by decreased surface albedo which leads to increasing soil surface temperatures and subsequent evaporation of soil water as observed by Oguntunde et al. (2008).

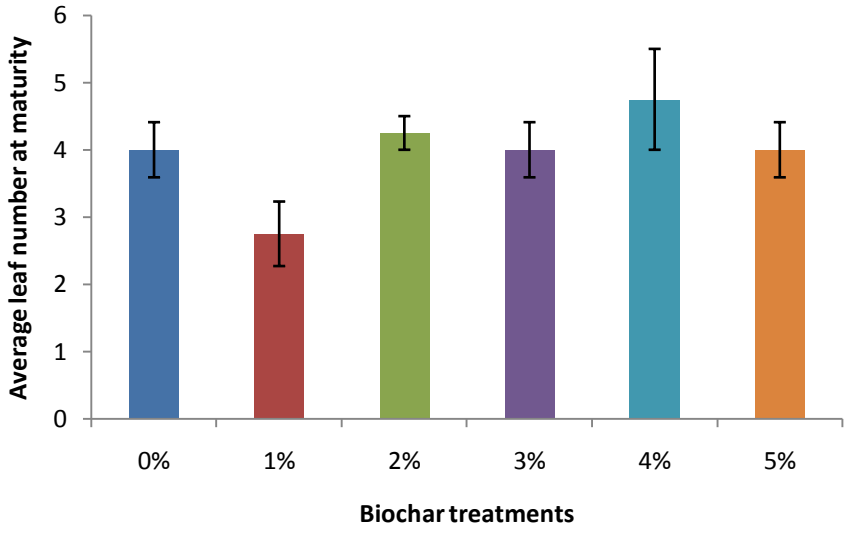

Figure 7. Average number of leaves of lettuce at 6 WAT as influenced by biochar applications. Error bars represent S.E at $P < 0.05$.

Further investigations into the treatment effects of biochar on leaf number at maturity, indicated that there were no significant differences between treatments ($P > 0.05$) (Figure 7). However, treatment A4 had the highest leaf number at maturity, representing an increase of 119 % compared to the control. This is followed by treatment A2 with increases

of 106 % compared to the control, whilst teatment A1 had the least, representing a decline of 69 % compared to the control. Treatments A3 and A5 were however similar in leaf number at maturity and were also not different compared to the control. Again, as indicated in the bar chart (Figure 7), it was revealed that there were no significant differences between biochar treatments and the control, as leaf numbers at maturity did not follow any particular pattern. This implies that biochar additions did not lead to increases in number of leaf at maturity.

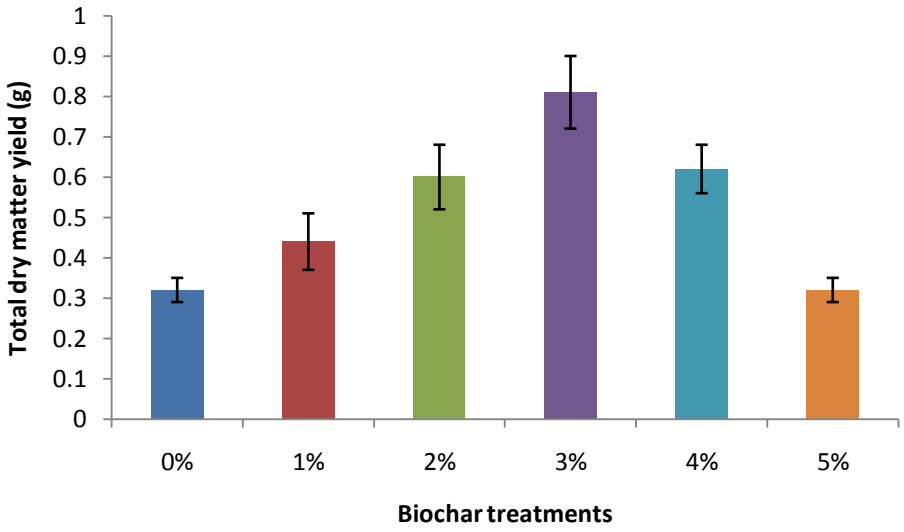

Figure 8. Effect of biochar on dry matter yield of lettuce at 6 WAT. Error bars represent S.E at $P < 0.05$.

The total dry matter yield of lettuce was significantly different ($P < 0.05$) among treatments. It was observed that increasing biochar rates led to corresponding yield increases, except with 4 and 5 % biochar rates. From the study, 3% biochar recorded the highest mean total dry matter yield of 0.81 g / pot, whilst the least was recorded by both the control and 5 % biochar, an average yield of 0.32 g / pot. The total dry matter yield of 1 % and 3 % biochar rates represent 253 and 100 % increases, respectively, compared to the

control. There was no significant difference between the total dry matter yield in the control and 5 % biochar treatment. The increases in total dry matter yield with increasing rates of biochar reached its optimum at 3 % and declined after 4 % biochar rate. The increases in total dry matter yield with increasing rates of biochar could be as a result of improvement in increasing soil pH, nitrogen and available P (Chapter Seven, Table 5). However, the decline in total dry matter yield as experienced in 4 and 5 % biochar rates could be attributed to P fixation due to pH increases as this was evident from the P level in the post harvest soil analysis (Chapter Seven, Table 5).

Similar to findings of this study total dry matter yield increases resulting from increasing biochar rates was reported by Uzoma et al. (2011) when they investigated the effect of cow manure biochar on maize productivity under sandy soil. They reported dry matter yields of 102, 211 and 172 % for biochar rates of 10, 15 and 20 t ha^{-1} of biochar rates, compared to the control. They observed yield decline at 20 t ha^{-1} of biochar application and attributed the decline to a high biochar C:N ratio thereby resulting in nitrogen immobilization and P fixation- resulting from higher soil pH. The latter reason could be true in my study as there was decline in available P at 4 % biochar rate. The decline in yield observed in higher biochar rates may be attributed to reduction in surface albedo as higher biochar rates had visible biochar on the soil surface. Oguntunde et al (2008) reported that reduction in surface albedo may lead to soil surface heating and induce higher surface temperatures, thus increasing evaporation of the soil moisture available to the crops. Further investigations should be carried out to explain the yield decline with higher levels of biochar application.

Conclusions

The experiment indicated that significant differences existed among biochar treatments effect on height of lettuce. That increasing biochar rates increased the height of lettuce. However, the increments in heights generally plateaued at the 3 % biochar rate and begins to decline with 4 % and 5 % biochar applications. It is therefore appropriate that for effective growth of lettuce with respect to plant height, application of 3 % biochar is agronomically feasible.

The study also revealed that increasing rates of biochar would not significantly influence the leaf number at maturity. The study also indicated that, total dry biomass was significantly different among treatments. This means that the application of up to 3 % biochar has the potential of increasing the yield of lettuce on this nutrient impoverished Oxisol in the Western Region of Ghana. Further experiment was carried out to determine the effect biochar in addition to organic amendments would have on the growth and yield of lettuce.

CHAPTER SIX

EFFECTS OF COMBINED APPLICATIONS OF CORN COB BIOCHAR AND POULTRY MANURE ON THE GROWTH AND YIELD OF LETTUCE (*Lactuca sativa* L)

Introduction

The apparent high fertility of 'Terra preta' soils in the Amazon rainforest has ignited recent surge in research to measure the immediate effect of biochar additions to soil on plant growth. There have been reported yield responses of over 300 % with varying biochar applications ranging between 0.5 to 135 t ha^{-1} (Sohi et al., 2009) . However, other researchers have advocated for external nutrient supplies to biochar to ensure high productivity and to increase the positive response from the biochar amendments. Positive benefits from poultry manure and biochar combinations have been observed by Glaser (2007).

For a successful soil management regime in the humid tropics, maintenance of appropriate soil organic matter and biological nutrient cycling is crucial. Practices such as cover cropping, mulching, composting or manuring have been a success, generally because of nutrient supplies to crops, rapid nutrient cycling from microbial biomass and efficiency in mineral fertilization (Goyal et al., 1999; Trujillo, 2002). In all these practices, the benefits in the tropics have been temporary due to high decomposition rates

(Jenkinson & Ayanaba, 1977). Again, the added organic matter is usually mineralized to CO_2 within only a few cropping seasons (Bol et al., 2000).

Therefore, there is the need to provide an additional soil management option which will overcome some of these limitations.

Biochar additions to soil as an amendment were necessitated by the high fertility of Amazonian Dark Earth (ADE) soils with biochar which sharply contrasts with adjacent upland acid soils with low fertility (Lehmann et al., 2003b).

In Ghana, the use of biochar in soil productivity management has not received much research attention. This study, therefore, sought to evaluate the contribution of biochar to soil fertility improvement.

The objective of this study was to evaluate the effects of biochar in combinations with poultry manure on the growth and yield of lettuce (*Lactuca sativa* L.).

Materials and Methods

A pot experiment was carried out between mid December, 2011 and mid January, 2012 on an Oxisol. The experiment was set up in pots at the University of Cape Coast Research and Teaching farm.

The soil used in this study has earlier been described under chapter five pages 60 to 61 of this thesis.

Experimental Setup

The pot experiment was conducted with a soil sample taken from 0–20 cm layer, air-dried, and passed through a 2.0 mm sieve. The experimental design was factorial arranged in completely randomized design with four replications, giving a treatment total of 72. There were two main treatments:

A, representing biochar and B, representing poultry manure. Treatment A had six (6) levels and was as follows:

Ao =0 % (0 t ha^{-1} equivalent) Control (soil only).

A1 =1 % (26 t ha^{-1} equivalent) biochar on weight basis.

A2 =2 % (52 t ha-1 equivalent) biochar on weight basis.

A3 = 3 % (78 t ha^{-1} equivalent) biochar on weight basis.

A4 =4 % (104 t ha^{-1} equivalent) biochar on weight basis.

A5 =5 % (130 t ha^{-1} equivalent) biochar on weight basis.

Treatments B had three (3) levels and were as follows:

Bo= Absolute control (soil only).

B1= Poultry manure at 10 t ha^{-1}.

B2= Poultry manure at 5 t ha^{-1}.

Treatments A and B were combined to evaluate their interactions on the lettuce plants. Therefore, the following interactions were also established:

A1B1= 1 % (26 t ha^{-1} equivalent) biochar+10 t $ha^{-1}$of poultry manure.

A1B2= 1 % (26 t ha^{-1} equivalent) biochar+5 t $ha^{-1}$of poultry manure.

A2B1= 2 % (52 t ha^{-1} equivalent) biochar+10 t $ha^{-1}$of poultry manure.

A2B2= 2 % (52 t ha^{-1} equivalent) biochar+5 t $ha^{-1}$of poultry manure.

A3B1= 3 % (78 t ha^{-1} equivalent) biochar+10 t $ha^{-1}$of poultry manure.

A3B2= 3 % (78 t ha^{-1} equivalent) biochar+5 t $ha^{-1}$of poultry manure.

A4B1= 4 % (104 t ha^{-1} equivalent) biochar+10 t $ha^{-1}$of poultry manure.

A4B2= 4 % (104 t ha^{-1} equivalent) biochar+5 t $ha^{-1}$of poultry manure.

A5B1= 5 % (130 t ha^{-1} equivalent) biochar+10 t $ha^{-1}$of poultry manure.

A5B2= 5 % (130 t ha^{-1} equivalent) biochar+5 t $ha^{-1}$of poultry manure.

Air-dried soil, biochar –amended soils with or without poultry manure (1 kg equivalent) were packed into plastic cylindrical pots (11.5 cm in diameter and 11 cm high) to achieve a bulk density of 1.3 Mg m^{-3}. Manures were added in equivalent amounts to supply 100 kg N ha^{-1} to the pots before planting as recommended by Grubben and Denton (2004). All the pots were then wetted up to 60 % of field capacity using distilled water. Seedlings were transplanted into pots after 2 weeks of germination at a seedling per pot. The pots were placed individually in shallow trays and regularly watered to maintain water content at approximately 60 % of field capacity using distilled water, throughout the 42 days duration of the experiment. The plants were harvested at 6 weeks after transplanting (WAT), fresh and total dry matter (biomass) as well as leaf number at maturity were determined. Before the total dry matter determination was done, plants from treatments were measured for growth by measuring the longest leaf of each plant from the node of the stem and the average taken for that particular treatment. Total dry matter was determined by oven drying the biomass at 70 °C to a constant weight.

Results and Discussion

Figure 9 indicates the height of lettuce plants as affected by the biochar rates of 0, 1, 2, 3, 4, and 5 %; poultry manure rates of 0, 5 and 10 t ha^{-1} as well their respective interactions over the 6 weeks period of observations.

The heights of lettuce were taken at the 6^{th} week after transplanting and the results indicated that there were significant differences among treatments ($P < 0.05$) (Figure 9).

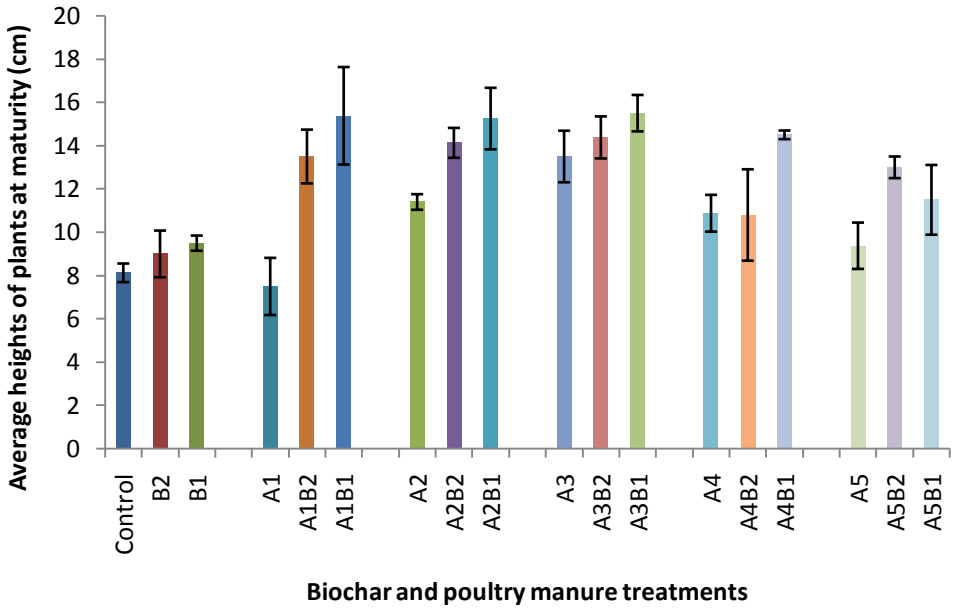

Figure 9. Effect of biochar and poultry manure treatments on height of lettuce at 6 WAT. Error bars represent S.E at $P < 0.05$

Biochar application resulted in lettuce height which ranged from 7.5 cm to 9.4 cm compared to that measured in unamended control, which was 8.1cm. Among the sole biochar treatments, 1 % biochar recorded the least ($P < 0.05$) plant height, whilst 3 % biochar recorded the highest ($P < 0.05$) value of 13.5 cm. The results indicated a decline in height with 1% biochar application compared to the unamended control. However, this decline was overcome with 5 t ha^{-1} of poultry manure application (Figure 9) that led to a net increase in height of 189 % compared to the unamended control and 205 % compared to the 1 % biochar treatment and 5 t ha^{-1} of poultry manure application alone. This is an indication of a positive synergy between the poultry manure and biochar at these rates. Increasing biochar rates also led to increases in heights of plants with 3 % biochar resulting in the highest height of 13.5 cm compared to the control. Furthermore, the increments in the rates of poultry manure from 5 t ha^{-1} to 10 t ha^{-1} with 1 % biochar rate also led to a significant height effect

compared to both the unamended control and the amended controls of 5 t ha^{-1} and 10 t ha^{-1} of poultry manure. This observation could be attributed to increasing plant nutrient supply from poultry manure as well as the improvement in soil physical conditions associated with biochar applications.

The analysis of variance on biochar and poultry manure interactions did not show significant effect ($P > 0.05$) on the heights of lettuce amongst treatments.

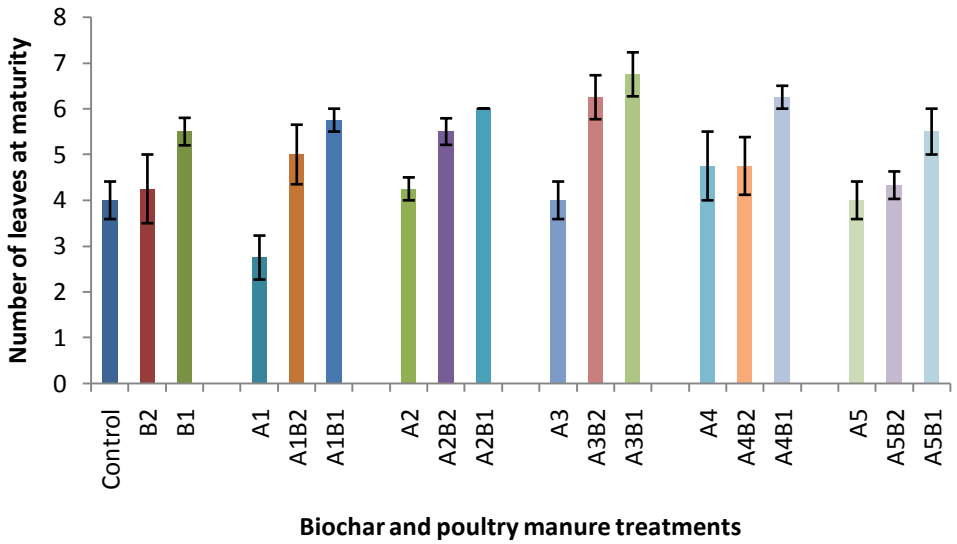

Figure 10. Effect of biochar and poultry manure applications on leaf number of lettuce at 6 WAT. Error bars represent S.E at $P < 0.05$.

The application of biochar sole treatments indicated a significant effect ($P < 0.05$) on the number of leaves at maturity. However, biochar effect on number of leaves at maturity did not show definite trend (Figure 10). As was observed in plant height for 1 % biochar rate, same can be said of this rate on number of leaves at maturity as there was a decline compared to both unamended and amended controls. The lowest rate of biochar, 1 %, had an average leaves number of 2.75, whilst the highest biochar rate, 5 %, had 4,

whereas the unamended control had average leaves number of 4. Compared to the unamended control, 1 % biochar had an increment of 69 %, whilst 5 % biochar had an increment of 100 %. The decline in the leaves number at maturity for 1 % biochar compared to the unamended control was nullified with the addition of 5 tons ha^{-1} of Poultry manure (PM) and this led to an increase of 125 % and 144 % for 10 t ha^{-1} of PM. The positive interaction effect observed for 1 % biochar with 5 and 10 t ha^{-1} could be attributed to nutrient supplies from PM decomposition leading to nutrient mineralization and availability.

The interaction between biochar and PM treatments did not show any significant effect ($P > 0.05$) on the number of leaves at maturity.

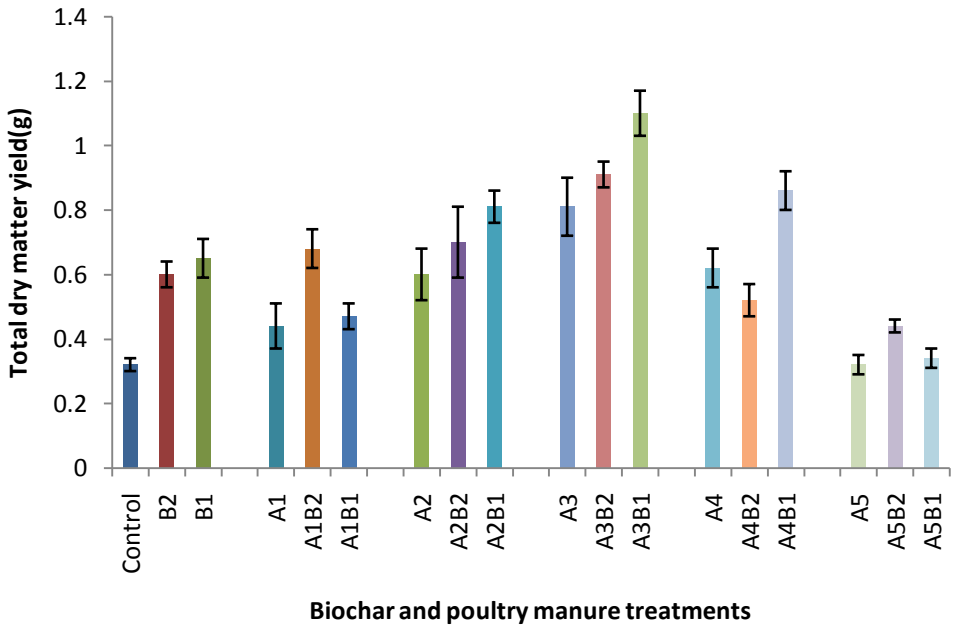

Figure 11. Effect of biochar and poultry manure applications on dry matter yield of lettuce at 6 WAT. Error bars represent S.E at $P < 0.05$

The results on the total dry matter as affected by solitary biochar applications indicates that there were significant differences ($P< 0.05$) (Figure 11) amongst treatments. Amongst the solitary biochar treatments, average

yields recorded ranged from 0.32 g to 0.81 g, with the unamended control and 5 % biochar treatment recording the lowest (0.32 g), whereas 3 % biochar recording the highest (0.81 g). Compared to the unamended control, 1 % biochar had 137 % total dry matter (TDM), whilst in comparison to the amended controls of 5 tons ha^{-1} and 10 t ha^{-1} of PM, this yield is translated to mean 73 % and 68 % TDM, respectively. The addition of 5 and 10 t ha^{-1} of poultry manure (PM) to 1 % biochar led to a positive synergy effect resulting in yield increases of 147 and 213 %, respectively, compared to their individual yields of 137 % for 1 % biochar and 188 and 203 % for 5 and 10 t ha^{-1} of poultry manure. The biochar-PM interaction led to a positive synergy leading to yield increases. These observation was evident in almost all biochar rates with their respective PM rates. These trends also led to significant effects ($P< 0.05$) between biochar and PM intreactions in the analysis of variance. The decreases in total dry matter yields of lettuce at 4 % and 5 % biochar and PM interaction could be attributed to N deficiencies resulting from N immobilization emanating from higher C:N ratios of biochar. The decline in yield could also be due to imbalances in the soil carbon pool. Krull et al (2003, 2004) explained the need for varying sources of SOC to be kept balanced and that imbalances between sources could lead to detrimental consequences on soil functions. These findings confirm a study by Chan et al.(2007) who reported increases in biomass production in beans (*Phaseolus vulgaris* L) with biochar additions of 30 and 60 g kg^{-1} , but observed biomass yield decline at 90 g kg^{-1} of biochar applications. The decreases in biomass prodcution associated with increases in biochar concentrations could be attributed to high

C:N ratios of biochar in the soil leading to a net immobilization of nitrogen, a phenomenon known as the ‘charcoal effect’.

Conclusions

Increasing biochar rates led to significant positive effect on height, number of leaves at maturity and on total dry matter yield of lettuce ($P < 0.05$).

Biochar and poultry manure interactions had positive significant effects on number of leaves at maturity and on total dry matter yield ($P < 0.05$) but not on heights of lettuce at maturity.

Application of biochar rate of 3 % with or without poultry manure significantly increased growth and yield of lettuce.

Growth and yield declines at higher biochar rates can largely be attributed to N immobilization and imbalances in soil organic carbon pools resulting from high C:N ratios of biochar and effect of soil priming.

CHAPTER SEVEN

EFFECTS OF CORN COB BIOCHAR ON SOME PROPERTIES OF AN OXISOL

Introduction

Biochar is a product of thermal decomposition of biomass produced by the process called pyrolysis. Biochar has been found to be biochemically recalcitrant as compared to un-charred organic matter and possesses considerable potential to enhance long-term soil carbon pool (Lehmann et al. 2006). Biochar has been shown to improve soil structure and water retention, enhance nutrient availability and retention, ameliorate acidity, and reduce aluminium toxicity to plant roots and soil microbiota (Glaser et al. 2002a).

In Sub-Saharan Africa, conversion of forest to small-scale permanent agricultural land accounts for 60 % of land-use change (FAO, 2005) and is often followed by low or no use of nutrient amendments (Sanchez et al., 1997; Sanchez, 2002; Smaling et al., 2006). Both N and P deficiencies are widespread in sub-Saharan African agricultural soils and are the main causes of low crop productivity, especially in smallholder agriculture (Buresh et al., 1997; Sanchez et al., 1997; Haileslassie et al., 2006). Under these conditions, crop production relies on SOM decomposition and mineral weathering as sources of plant nutrients (Donovan and Casey, 1998; Sanchez and Swaminathan, 2005). Although the importance of fertilizer in the tropics has been recognized, its use is low (FAO, 2003). The lack of fertilizer use is

correlated with clearing of natural lands for agriculture and land degradation in Africa (Smaling et al., 2006). The reduced productivity of cultivated areas contributes to greater hunger in the region (Sanchez & Swaminathan, 2005). Because current recommendations for fertilizer application rates are low and not site specific (FAO, 2003), adoption of these recommendations often does not resolve nutrient depletion problems (Zingore et al., 2007).

The fertility of highly weathered Oxisols in the tropics is low, and soil organic matter plays a major role in sustaining soil productivity. Therefore, long-term use of these soils is not sustainable without nutrient inputs where soil organic matter is depleted (Tiessen et al., 1994). Moreover, these soils have low nutrient- retention capacity and high permeability and as a result strong tropical rainfalls cause leaching of mobile nutrients such as those applied with nutrient fertilizers (Hölscher et al., 1997a; Giardina et al., 2000; Renck & Lehmann, 2004).

The shelling of maize in Ghana leaves behind large quantities of corn cobs. These corn cobs are either left to decompose, burnt in the open or used as fuel for other cottage processes. And any of these processes lead to the production of gases, particularly CO_2, that are implicated in climate change. Other gases released include, CO, NH_4, N_2O and other oxides of nitrogen (NO_x) as well as particulate matter (PM). In order to avoid the emissions of these gases, the corn cob biomass can be charred to release energy and produce biochar which can be used as a soil amendment.

However, research findings on the use of biochar for improving soil physicochemical properties have been varied largely due to differences in soil types used, varying biochar application resulting from varying feedstocks and

pyrolysis conditions and even differences on the test crops used in those experiments. Therefore, the objective of this study was to investigate the effect of corn cob biochar on some soil properties of an Oxisol.

Materials and Methods

Production and characterization of corn cob biochar

The production of corn cob biochar followed the processes as described in chapter five, pages 59 to 60.

The corn cob biochar was characterized for pH, total carbon, total nitrogen, total P and electrical conductivity as described earlier in chapter three pages 21 to 35 of this thesis.

Soil

The soil used in this study has been described earlier in chapter three page 60 of this thesis.

Experimental Setup

An incubation experiment was conducted with the soil sample that has been prepared. The experimental design used was the completely randomized design comprising six treatments and four replications giving a treatment total of 24. The biochar was incorporated into soil on weight per weight basis as follows:

(Ao)= 0 % (0 t ha^{-1} equivalent) control (soil only).

(A1)= 1 % (26 t ha^{-1} equivalent) weight per weight.

(A2)= 2 % (52 t ha^{-1} equivalent) weight per weight.

(A3)= 3 % (78 t ha^{-1} equivalent) weight per weight.

(A4)= 4 % (104 t ha^{-1} equivalent) weight per weight.

(A5)= 5% (130 t ha^{-1} equivalent) weight per weight.

Air-dried soil, biochar –amended soils (1 kg equivalent) were packed into plastic cylindrical pots (11.5 cm in diameter and 11 cm high) to achieve a bulk density of 1.3 Mg m^{-3}. All the pots were then wetted up to 60 % of field capacity using distilled water. The pots were placed individually in shallow trays and regularly watered to maintain water content at approximately 60 % of field capacity using distilled water, throughout the 30 days duration of the experiment.

Soil Analyses

At the end of the growth period (6 weeks), the soil from each pot was air-dried, mixed thoroughly, and crushed gently to pass through a 2 mm sieve. The <2-mm samples were then analyzed for pH, total organic C, total N, extractable P, and exchangeable bases (Ca^{2+}, Mg^{2+}, and K^{+}) determined according to the method described by Rowell (1994). Exchangeable acidity (Al+H) was determined by the procedure described by Anderson and Ingram (1993). The pH was measured in 1: 2.5 soil to water ratio, total organic carbon was determined by the wet oxidation method of Walkley and Black (1934). Total nitrogen was determined by acid digestion and nitrogen analyzed by the micro-kjeldahl method. Extractable P was determined by using Bray No.1 ex tract, and reading done by using the spectrophotometer at 882 nm.

Results and Discussion

The results on the applications of the biochar rates on some selected soil properties of an Oxisol are presented in Table 5.

Table 5: Effect of Biochar Application on Some Chemical Properties of Postharvest Soil

TREATMENT	pH	OC	N	P(mg/kg)	Ca^{+2}	Mg^{+2}	K^{+}	$Al^{+3}+H^{+}$	ECEC
		%			$cmol_c kg^{-1}$				
0 % biochar	3.73f	0.62a	0.041b	7.1d	0.95a	0.43b	0.15f	1.30a	2.83d
1 % biochar	5.05e	0.59a	0.063a	11.5cd	0.79b	0.87a	0.86e	1.26a	3.78c
2 % biochar	5.40d	0.61a	0.069a	13.1bcd	0.81b	0.95a	1.49d	0.58b	3.83c
3 % biochar	5.69c	0.58a	0.073a	20.3ab	0.75b	0.91a	1.91c	0.42c	4.00c
4 % biochar	5.91b	0.63a	0.075a	16.6bc	0.79b	1.17a	2.40b	0.41c	4.76b
5 % biochar	5.99a	0.63a	0.078a	26.1a	0.97a	1.03a	2.79a	0.31c	5.1a
CV(%)	1.0	5.6	15	31.7	12	26.4	3.7	13.5	5.2
S.E	0.0564	0.0345	0.0099	5.0	0.1016	0.2359	0.0588	0.0979	0.2130

OC=organic carbon,N=nitrogen,P=phosphorus, Ca^{+2}=Exchangeable calcium, Mg^{+2}=Exchangeable magnesium, K^{+}=Exchangeable potassium,$Al^{+3}+H^{+}$=Exchangeable acidity,ECEC=Effective cation exchange capacity.

Table 6: Pearson Correlation (r) Matrix for Some Selected Chemical Properties of Postharvest Soil

	Ph	OC	AVP	Ca	Mg	K	Al+H	ECEC
pH	-	-	-	-	-	-	-	-
OC	0.19	-	-	-	-	-	-	-
AVP	0.71**	0.16	-	-	-	-	-	-
Ca	-0.09	0.29	-0.01	-	-	-	-	-
Mg	0.63**	0.05	0.44*	-	-	-	-	-
				0.52**				
K	0.98**	0.19	0.76**	-0.10	0.66**	-	-	-
Al+H	-	-0.19	-	0.16	-	-	-	-
	0.95**		0.69**		0.61**	0.93**		
ECEC	0.89**	0.19	0.71**	-0.07	0.77**	0.93**	-	-
							0.77**	

*,** significant at P<0.05 snd P<0.01, respectively; OC= organic carbon; AVP= available phosphorus; Ca, Mg, K,= exchangeable forms; Al+H= exchangeable acidity; and ECEC= effective cation exchange capacity

Biochar addition significantly (P < 0.05) increased soil pH relative to the control (Table 5). Increase in soil pH measured in the 1 % and 5 % biochar treatments were 135 % to 161 % higher than in the control (Table 5). The 5 % biochar treatment yielded a pH increase of 2.26 units over the control whilst the 1 % biochar treatment increased soil pH by 1.32 units higher than in the control. Biochar treatments of 2 %, 3 % and 4 % had pH increases of 1.67 units, 1.96 units and 2.18 units, respectively, compared to the control. Similar trend was observed by Chan et al.(2007) when they investigated the agronomic values of green waste biochar in a pot trial. The reduction in the acidity of the soil could be attributed to the liming ability of the biochar which

was observed to be alkaline (Chapter Three, Table 3). Raison (1979) explained that the increase in soil pH with the addition of biochar can be attributed to ash accretion as ash residues are generally dominated by carbonates of alkali and alkaline earth metals, sesquioxides, phosphates and small amounts of organic and inorganic N.

Application of biochar to the soil showed significant difference ($P < 0.05$) on total nitrogen content of the soil. There was significant difference between total nitrogen of the unamended soil and that of the biochar amended soil, but there were no significant difference of total nitrogen amongst biochar treatments (Table 5) at ($P < 0.05$). Further, increasing biochar rates led to increases in total nitrogen content of the soil compared to the unamended soil. This increases could be attributed to the ash content of the biochar which is known to contain small amounts of organic and inorganic N (Raison, 1979).

The effect of biochar additions on soil organic carbon was observed and the results indicated no significant differences ($P < 0.05$) between treatments (Table 5). However, there were some treatment effects that were observed among the biochar treatments. Treatments of 4 % and 5 % biochar had a positive value of 0.01 % organic carbon increases over the control, whiles treatments of 1 %, 2 % and 3 % biochar additions had a negative effect on levels of organic carbon determined with values of -0.02 %, -0.01 % and -0.04 %, respectively, compared to the control. The decreases in soil organic carbon (SOC) in most biochar treated soils compared to the unamended soil could be as a result of what is termed " priming effect". This is the acceleration of soil carbon decomposition by fresh carbon input to soil (Fontaine et al., 2004). The acceleration of the decomposition of SOC as a

result of fresh carbon (C) input is attributed to changes in the microbial community composition. A study by Fontaine et al (2004) revealed that the decomposition rate of soil humus stock in a savannah soil increased by 55 % following cellulose additions. This was further confirmed by Kuzyakov et al (2009) when they observed that the Black Carbon (BC) in soil underwent increased decomposition upon the addition of glucose to the soil. They concluded that the decomposition of the BC came about through the metabolites of the microorganism after glucose decomposition as it was evident in the very slow rate the BC had decomposed compared to the glucose. The mechanism which stimulates microbial growth and proliferation may be from changes in pH of the soil, changes in water-filled pore spaces, changes in habitat structure or changes in nutrient availability.

The availability of phosphorus (P) with biochar additions was investigated due to the fact that such soils are highly deficient in available P as a result of soil acidity leading to increasing complexation of Al and Fe oxides with available P. Biochar additions to the soil was observed to be significantly different ($P < 0.05$) (Table 5). Available P was highest in treatment with 5 % biochar additions (26.1 mg/kg) which represents an increase of 368 % compared to the control, whilst treatment with 1% biochar recorded the least available P (11.5 mg/kg) (162 % increases over the control). The increases in available P with increasing biochar additions could largely be attributed to the corresponding increases in the pH of the soil as well as the decreases in exchangeable acidity (Table 5). The explanation given to the mechanism that led to increases in available P is thought to be due to decreasing solubility of Al emanating from increasing soil pH and the increases in complexing

between Al and charged negative surfaces of biochar also resulting from increasing CEC. The correlation matrix showed a positive and strong significant relationship between available P and pH ($P < 0.01$; $r = 0.71$) and ECEC ($P < 0.01$; $r = 0.71$) (Table 6), whereas the relationship between available P and exchangeable acidity from the correlation matrix indicates a negative and strong significance ($P < 0.01$; $r = -0.69$). However, increasing levels of available P with corresponding increases in biochar additions as observed has also been reported by Chan et al (2007, 2008).

Biochar applications resulted in significant increases in exchangeable Ca ($P < 0.05$). Amongst the biochar treatments, 5 % biochar application led to the highest exchangeable Ca, however, this was not significantly different from the control. The biochar application rates of 1 % to 4 % did not lead to significant differences in exchangeable Ca levels. This observation made is contrary to what has been observed by Chan et al. (2007) and Uzoma et al. (2011). The high level of exchangeable Ca recorded for 5 % biochar rate could be attributed to significant increase in pH (Table 5) resulting from this application, which resulted in release of Ca in to solution. However, the decline in exchangeable Ca recorded by 1 % to 4 % biochar rates, compared to the control, is unclear, since there were significant reduction in their pH compared to the control and therefore should have significant increases in their exchangeable Ca.

From the analysis of variance, there were significant differences ($P < 0.05$) of exchangeable Mg between biochar treated soils and the control. Generally, the content of exchangeable Mg^{+2} increased with increasing biochar rates, although, there were no significant differences among biochar

treated soils (Table 5). Increase in exchnageable Mg^{+2} with increasing biochar rates have been reported by Uzoma et al. (2011). The increase in exchangeable Mg^{+2} with increasing biochar rates could be attributed to the increases in pH and the ECEC of biochar applied soils. The correlation matrix indicates a positive and strong significance between exchangeable Mg^{+2} and pH ($P < 0.01$: $r = 0.66$) and ECEC ($P < 0.01$: $r = 0.77$) (Table 6).

Exchangeable acidity was significantly ($P < 0.05$) reduced by biochar additions to the soil. The reduction of exchangeable acidity with increasing biochar rate could be attributed to the steady increases in pH and ECEC, leading to the decline in solubility of Al in soil solution as well as increase in Al chelation with negatively charged surfaces of biochar-soil interactions. The decline in exchangeable acidity was highest with 5% biochar additions resulting in a decline of > 70 %. Similar observations were made by Chan et al. (2007) who reported as much as > 50% reduction in exchangeable Al at 50 and 100 t ha^{-1} of biochar application.

Biochar application significantly ($P < 0.05$) increased the ECEC of the soil. Increasing biochar rates led to increases in ECEC of the soil amongst the treatments. The highest ECEC was produced by the application of 5% biochar that recorded a value of 5.1 compared to the control value of 2.83, indicating a percentage increase of 180. Uzoma et al. (2011) also reported significant increase in the CEC of a sandy soil, with the highest biochar rate recording CEC increase of 170 % compared to the control. The general trend of increases in CEC of soils with biochar applications have been reported extensively in literature (Chan et al., 2007; 2008, Uzoma et al., 2011 and Nigussie et al., 2012). The increases in the ECEC of the soil with biochar

applications could be linked to increases in the levels of Mg, K and the pH of the soil. From the correlation matrix (Table 6), the following relationships were identified: a positive and strong significance between ECEC and Mg ($P < 0.01$; $r = 0.77$), ECEC and K ($P < 0.01$; $r = 0.93$), and ECEC and pH ($P < 0.01$; $r = 0.89$). The pH contributes to the ECEC by increasing amounts of negative charges on the surfaces of the soil-biochar interactions. The source of Mg could be as a result of increases in the soil pH which makes it readily available. Potassium availability and contribution to the ECEC could be from the ash component of the biochar.

Conclusions

The application of biochar to the soil was found to significantly increase pH, total nitrogen, total phosphorus, but not organic carbon.

The application of biochar led to significant increases ($P < 0.05$) in exchangeable bases such as Mg^{+2} and K^{+}, but significantly ($P < 0.05$) resulted in the decline of exchangeable acidity. This trend observed means the biochar can be used as liming material when added to strongly acidic soils thereby leading to reduction in soil acdity and increased nutrient availability to this nutrient poor soils.

The ECEC of the soil was significantly ($P < 0.05$) increased by addition of biochar. This leads to the overall improvement in the soil's capacity to hold and release nutrients. The increased ECEC can adsorb pollutants through reduction in nutrient leaching into underground waters.

CHAPTER EIGHT

GENERAL SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

An evaluation of the performance of the 'Lucia stove' using locally available plant biomass as feedstocks, and the effects of incorporating the biochar produced as soil amendment was carried out. To determine the performance of the stove, the following tests were done: burning duration, biomass consumption rate, biochar yield (dry weight), boiling duration, pH of residual water and flame characteristics. In order to evaluation the effectiveness of the biochar produced as a soil amendment, measurements were taken on number of leaves, height of plants at maturity and total dry matter yield of a lettuce test crop. Soil parameters that were measured after plant harvest were pH, soil organic carbon, available phosphorus, total nitrogen, exchangeable Ca^{+2}, Mg^{+2}, K^{+}, acidity and ECEC.

Six biochar treatments were applied: 0 %, 1 %, 2 %, 3 %, 4 % and 5 % on weight per weight basis, representing 0, 26, 52, 78, 104 and 130 t ha^{-1}, respectively. These treatments were further combined with three poultry manure rates of 0 t ha^{-1}, 5 t ha^{-1} and 10 t ha^{-1}, respectively in a completely randomized design.

The main objectives of the study included the evaluation of the 'Lucia stove' with locally available feedstocks to enable an assessment of the efficient use of the stove and characterization of the biochar produced. Other

objectives were an evaluation of the effect biochar either alone or with organic manure on the growth and yield of lettuce, and the evaluation of these treatments on selected chemical properties of the soil.

In the study of the evaluation of the Lucia stove, the CC feedstock brought water at room temperature to boil earlier than the OPP feedstock did. The OPP feedstock lasted 3 times longer than did the CC feedstock an implication of the earlier feedstock suitability as cooking fuel in our homes. The water used after quenching burning feedstocks recorded pH values of 10.2 for CC and 10.7 for OPP, an indication of their potential to be used as a liming material for acid soils. The test on the flame characteristics of these feedstocks indicated that CC had blue flames occurring earlier than in OPP, implying the higher burning power of the CC feedstock. Soot and tar coverage at the base of pots were noted in both feedstocks with CC recording 100 % coverage at the base of the pots whiles the OPP recorded about 70 %.

Biochar applications to the soil at the various rates showed differences on height but not on number of leaves at maturity ($P > 0.05$). Biochar at the applied rates did show significant differences ($P > 0.05$) on total dry matter of lettuce. However, in absolute value terms, the biochar rate that generally impacted positively on the growth and yield of lettuce compared to the unamended control was 3 % biochar.

Biochar application in combination with poultry manure showed significant differences ($P < 0.05$) among treatments in both growth and yield parameters observed. The treatment of 3 % biochar with 10 t ha^{-1} poultry manure was observed to show superiority in terms of growth and yield

measurements, while treatments beyond 3 % biochar addition were observed to lead to growth and yield declines.

The study revealed that there were significant increases in soil pH, total nitrogen, available phosphorus, exchangeable Mg and K, and ECEC, but decreased exchangeable acidity. However, the biochar applied did not significantly increase soil organic carbon (SOC).

The null hypotheses of the study on the growth and total dry matter yield should be rejected and the alternative accepted. The alternate hypothesis for sole biochar applications effects on the soil chemical properties should be accepted whilst the null should be rejected. On the hypothesis for the feedstock testing, the null is rejected whilst the alternate is accepted.

There is the need to conduct the experiment over a longer period of time to provide the opportunity to evaluate the residual effects of these treatments on the measured parameters so as to afford one better insight to biochar impacts on this type of soil for future recommendations to farmers. The study can further be enhanced by the analysis of plant nutrient uptake of the macro nutrients particularly N P and K so as to better explain biochar effects on the overall productivity of the test crop. Future research on this study could target the capture and measurement of some of the major global warming implicated gases such as CO_2, CH_4 and various oxides of nitrogen.

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APPENDICES

APPENDIX A

Table 1: Anova on the Effect of Biochar Rates on Height of Lettuce at Maturity

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR TREATMENT	5	100.127	20.025	5.62	0.003
RESIDUAL	18	64.082	3.560		
TOTAL	23	164.210			

Coefficient of variation=18.6%

Table 2: Anova on the Effect of Biochar Rates on the Number of Leaves of Lettuce at Maturity

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR TREATMENT	5	8.7083	1.7417	1.93	0.139
RESIDUAL	18	16.2500	0.9028		
TOTAL	23	24.9583			

Coefficient of variation=24.0%

Table 3: Anova on the effect of biochar rates on the total dry matter yield of lettuce (g)

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR TREATMENTS	5	0.331500	0.066300	11.16	<.001
RESIDUAL	18	0.106900	0.005939		
TOTAL	23	0.438400			

Coefficient of variation= 24.9%

APPENDIX B

TABLE OF ANALYSIS OF VARIANCE FOR BIOCHAR

POULTRY MANURE INTERACTION

Table 1: Anova on the Effects of Biochar and Poultry Manure Applications on Heights of Lettuce

SOURCES OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR	5	226.040	45.208	8.44	<.001
POULTRY M ANURE	2	150.910	75.455	8.44	<.001
BIOCHAR.POULTRY MANURE	10	89.317	8.932	1.67	0.114
RESIDUAL	52	278.582	5.357		
TOTAL	69	743.658			

Coefficient of variation= 19.2%

Table 2: Anova on the Effect of Biochar and Poultry Manure Applications on Number of Leaves at Maturity of Lettuce

SOURCES OF VARIATION	DREGREES OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR	5	12.0730	2.4146	2.87	0.023
POULTRY MANURE	2	48.2851	24.1425	28.69	<.001
BIOCHAR.POULTRY MANURE	10	13.6556	1.3656	1.62	0.127
RESIDUAL	51	42.9167	0.8415		
TOTAL	68	116.0000			

Coefficient of variation=18.3%

Table 3: Anova on the Effect of Biochar and Poultry Manure Applications on the Total Dry Matter of Lettuce at Maturity

SOURCES OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR	5	2.275400	0.455080	49.36	<.001
POULTRY MANURE	2	1.608100	0.804050	87.20	<.001
BIOCHAR. POULTRY MANURE	10	0.934550	0.093455	10.14	<.001
RESIDUAL	54	0.497900	0.009220		
TOTAL	71	5.315950			

Coefficient of variation=18.5%

APPENDIX C

TABLES OF ANALYSIS OF VARIANCE FOR SOIL CHEMICAL PROPERTIES.

Table 1: Anova on the Effect of Biochar Rates on the Soil pH

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR TREATMENTS	5	4.228171	0.845634	265.53	<.001
RESIDUAL	18	0.057325	0.003185		
TOTAL	23	4.285496			

Coefficient of variation= 1.0%

Table 2: Anova on the Effect of Biochar Rates on the Soil Organic Carbon

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILTY
BIOCHAR TREATMENTS	5	0.008628	0.001726	1.45	0.254
RESIDUAL	18	0.021416	0.001190		
TOTAL	23	0.030044			

Coefficient of variation= 5.6%

Table 3: Anova on the Effect of Biochar Rates on Available P

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILTY
BIOCHAR TREATMENTS	5	910.37	182.07	7.29	<.001
RESIDUAL	18	449.67	24.98		
TOTAL	23	1360.04			

Coefficient of variation= 31.7%

Table 4: Anova on the Effect of Biochar Rates on Exchangeable Acidity

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR TREATMENTS	5	199.0000	39.8000	75.41	<.001
RESIDUAL	18	9.5000	0.5278		
TOTAL	23	208.5000			

Coefficient of variation= 13.5%

Table 5: Anova on the Effect of Biochar Applications on Soil Nitrogen

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR TREATMENTS	5	0.0036445 3	0.00072891	7.41	<.001
RESIDUAL	18	0.0036445 3	0.00009840		
TOTAL	23	0.0054157 2			

Coefficient of variation= 15.0%

Table 6: Anova on the Effect of Biochar on Exchangeable Calcium

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR TREATMENT	5	0.19420	0.03884	3.76	0.017
RESIDUAL	18	0.18588	0.01033		
TOTAL	23	0.38008			

Coefficient of variation= 12.0%

Table 7: Anova on the Effect of Biochar on Exchangeable Magnesium

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR TREATMENTS	5	1.22819	0.24564	4.42	0.008
RESIDUAL	18	1.00144	0.05564		
TOTAL	23	2.22962			

Coefficient of variation= 26.4%

Table 8: Anova on the Effect of Biochar on ECEC

SOURCES OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	VARIANCE RATIO	F PROBABILITY
BIOCHAR TREATMENT	5	11.48905	2.29781	50.65	<.001
RESIDUAL	18	0.81662	0.04537		
TOTAL	23	12.30566			

Coefficient of variation= 5.2%

APPENDIX D

Table 1: Data on the total dry matter yield of lettuce (g)

Biochar treatment	Replication	Dry matter yield
Ao	1	0.23
Ao	2	0.2
Ao	3	0.5
Ao	4	0.23
A1	1	0.17
A1	2	0.15
A1	3	0.16
A1	4	0.16
A2	1	0.3
A2	2	0.34
A2	3	0.26
A2	4	0.29
A3	1	0.59
A3	2	0.36
A3	3	0.34
A3	4	0.46
A4	1	0.52
A4	2	0.51
A4	3	0.45
A4	4	0.45
A5	1	0.19
A5	2	0.19
A5	3	0.21
A5	4	0.18

Table 2: Data on the height of plants at harvest (cm)

Treatment	R1	R2	R3	R4
Ao	7	8.5	9	8
B1	10	8.5	10	9.5
B2	12	7	9	8
A1	10	7	4	9
A2	12	10.6	11	12
A3	17	12	12	13
A4	12.5	11.5	8.5	11
A5	8	12.5	9	8
A1B1	13.5	10	18	20
A1B2	14.5	11	16.5	12
A2B1	16.5	17	16.5	11
A2B2	15	12.5	15.5	13.5
A3B1	15	17.5	16	13.5
A3B2	13.5	17	12.5	14.5
A4B1	14.5	15	14.5	14
A4B2	11	12	9.5	7.5
A5B1		14	8.5	12
A5B2	14		12.5	12.5

Table 3: Number of lettuce leaves at maturity

Treatment	R1	R2	R3	R4
Ao	3	4	4	5
B1	6	6	5	5
B2	5	3	6	3
A1	4	2	2	3
A2	5	4	4	4
A3	5	3	4	4
A4	4	6	3	6
A5	3	5	4	4
A1B1	6	6	6	5
A1B2	6	5	7	4
A2B1	6	6	6	6
A2B2	6	5	5	6
A3B 1	6	7	8	6
A3B2	7	6	5	7
A4B1	7	6	6	6
A4B2	6	5	5	3
A5B1		5	6	
A5B2	4		5	4

Table 4: Data on pH of biochar treated soil

Treatment	Replications	pH
Ao	1	4.87
Ao	2	4.9
Ao	3	4.83
Ao	4	4.9
A1	1	5.1
A1	2	4.93
A1	3	5.13
A1	4	5.03
A2	1	5.37
A2	2	5.4
A2	3	5.4
A2	4	5.43
A3	1	5.7
A3	2	5.67
A3	3	5.7
A3	4	5.7
A4	1	5.8
A4	2	5.87
A4	3	5.97
A4	4	6
A5	1	5.96
A5	2	6
A5	3	6
A5	4	6.03

Table 5: Data on Soil Organic Carbon of Biochar Treated Soil

Treatment	Replications	S O C (%)
Ao	1	0.638182
Ao	2	0.675
Ao	3	0.57541
Ao	4	0.605172
A1	1	0.57541
A1	2	0.594915
A1	3	0.57541
A1	4	0.605172
A2	1	0.626786
A2	2	0.615789
A2	3	0.615789
A2	4	0.585
A3	1	0.594915
A3	2	0.54
A3	3	0.566129
A3	4	0.65
A4	1	0.65
A4	2	0.65
A4	3	0.626786
A4	4	0.594915
A5	1	0.605172
A5	2	0.65
A5	3	0.688235
A5	4	0.594915

Table 6: Data on Total Nitrogen of Biochar Treated Soil

Treatment	Replications	N(mg kg^{-1})
Ao	1	0.04875
Ao	2	0.04691
Ao	3	0.018764
Ao	4	0.04875
A1	1	0.066937
A1	2	0.060413
A1	3	0.062156
A1	4	0.062156
A2	1	0.070365
A2	2	0.066937
A2	3	0.071036
A2	4	0.0663
A3	1	0.069708
A3	2	0.071719
A3	3	0.078
A3	4	0.071719
A4	1	0.073849
A4	2	0.078
A4	3	0.071036
A4	4	0.077242
A5	1	0.062156
A5	2	0.065061
A5	3	0.102238
A5	4	0.080507

Table 7: Data on Available Phosphorus of Biochar Treated Soil

Treatment	Replication	P (mg L^{-1})
Ao	1	7.623965
Ao	2	6.852052
Ao	3	7.609286
Ao	4	6.474874
A1	1	14.69425
A1	2	8.062075
A1	3	11.44054
A1	4	11.66213
A2	1	10.90321
A2	2	13.18149
A2	3	13.34423
A2	4	14.97157
A3	1	19.08178
A3	2	26.60937
A3	3	17.43795
A3	4	17.90316
A4	1	22.82786
A4	2	21.46217
A4	3	8.290247
A4	4	13.95687
A5	1	30.92581
A5	2	20.12954
A5	3	35.74145
A5	4	17.57532

Table 8: Data on Exchangeable Calcium of Biochar Treated Soil

Treatment	Replication	Ca($cmol_c kg^{-1}$)
Ao	1	0.787402
Ao	2	1.197605
Ao	3	1.106719
Ao	4	0.796813
A1	1	0.795229
A1	2	0.796813
A1	3	0.785855
A1	4	0.787402
A2	1	0.86444
A2	2	0.792079
A2	3	0.788955
A2	4	0.790514
A3	1	0.707269
A3	2	0.86785
A3	3	0.712871
A3	4	0.710059
A4	1	0.790514
A4	2	0.785855
A4	3	0.792079
A4	4	0.793651
A5	1	0.878244
A5	2	1.111111
A5	3	0.948617
A5	4	0.950495

Table 9: Data on Exchangeable Magnesium of Biochar Treated Soil

Treatment	Replication	Mg($cmol_c kg^{-1}$)
Ao	1	0.708661
Ao	2	0.07984
Ao	3	0.474308
Ao	4	0.478088
A1	1	0.874751
A1	2	0.557769
A1	3	1.178782
A1	4	0.866142
A2	1	0.86444
A2	2	0.792079
A2	3	1.183432
A2	4	0.948617
A3	1	1.414538
A3	2	0.473373
A3	3	0.871287
A3	4	0.86785
A4	1	1.185771
A4	2	1.178782
A4	3	1.188119
A4	4	1.111111
A5	1	1.197605
A5	2	0.873016
A5	3	1.106719
A5	4	0.950495

Table 10: Data on Exchangeable Potassium of Biochar Treated Soil.

Treatment	Replication	K (c mol $_c$ kg^{-1})
Ao	1	0.186278
Ao	2	0.188881
Ao	3	0.187014
Ao	4	0.188504
A1	1	0.849125
A1	2	0.79987
A1	3	0.889362
A1	4	0.891113
A2	1	1.49232
A2	2	1.453496
A2	3	1.548651
A2	4	1.450623
A3	1	1.894291
A3	2	1.901764
A3	3	1.909296
A3	4	1.952209
A4	1	2.46151
A4	2	2.34651
A4	3	2.365096
A4	4	2.420533
A5	1	2.894467
A5	2	2.623513
A5	3	2.815321
A5	4	2.820896

Table 11: Data on Exchangeable Acidity of Biochar Treated Soil

Treatment	Replication	Al+H ($cmol_c kg^{-1}$)
Ao	1	1.377953
Ao	2	1.197605
Ao	3	1.581028
Ao	4	1.394422
A1	1	1.192843
A1	2	1.474104
A1	3	1.100196
A1	4	1.259843
A2	1	0.550098
A2	2	0.633663
A2	3	0.552268
A2	4	0.592885
A3	1	0.471513
A3	2	0.473373
A3	3	0.356436
A3	4	0.394477
A4	1	0.434783
A4	2	0.43222
A4	3	0.356436
A4	4	0.396825
A5	1	0.279441
A5	2	0.357143
A5	3	0.27668
A5	4	0.316832

Table 12: Data on Effective Cation Exchange Capacity of Biochar Treated Soil

Treatment	Replication	ECEC (c mol $_c$ kg^{-1})
Ao	1	3.060294
Ao	2	2.66393
Ao	3	3.349069
Ao	4	2.857827
A1	1	3.711948
A1	2	3.628555
A1	3	3.954195
A1	4	3.804499
A2	1	3.771298
A2	2	3.671318
A2	3	4.073306
A2	4	3.782639
A3	1	4.487612
A3	2	3.71636
A3	3	3.84989
A3	4	3.924595
A4	1	4.872578
A4	2	4.743366
A4	3	4.70173
A4	4	4.722121
A5	1	5.249756
A5	2	4.964783
A5	3	5.147337
A5	4	5.038718