THE INFLUENCE OF RICE HUSK BIOCHAR AND NITROGEN SOURCES ON THE GROWTH OF LOWLAND RICE ON AN EUTRIC GLEYSOL FROM WALEWALE

BY

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A THESIS SUBMITTED TO THE UNIVERSITY OF GHANA IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR M.PHIL SOIL SCIENCE

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July 2018

DECLARATION

I hereby declare that the thesis herein presented for the award of Master of Philosophy in Soil Science is a result of my investigation. All references to other authors' work as sources of information are duly acknowledged.

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DEDICATION

This work is dedicated to my dear wife Asana Salifu, the memory of my late parents Abdulai Gibrilla and Fatima Addy. Without their endless support and encouragement, thoughtful guidance and genuine care, I would not have achieved all I have achieved.

ACKNOWLEDGEMENTS

My utmost gratitude goes to The Almighty Allah for the gift of life to complete the study successfully, but for you, I would not have made it this far.

My sincere gratitude and deep appreciation goes to my supervisor, Dr. Mrs. Stella Asuming-Brempong for her guidance, support in helping me realize my potential. I am extremely grateful for the extent you went to make sure my work was done and completed on time. Allah richly bless you.

I wholeheartedly extend my thanks to Dr. Eric K. Nartey, my co-suprvisor for his critique and keeping me on track throughout my research work programme.

To all the Lecturers of the Department, I say a very big thank you and ask for Allah's blessings for your support, suggestions, encouragement and love they showed me throughout my two-year study.

My acknowledgement will not be complete without expressing my profound gratitude to West Africa Agricultural Productivity Programme (WAAPP) and USAID-Ghana/University of Ghana Institutional Capacity Building for Agricultural Productivity Project for their financial support towards my academic work.

Finally, my special thanks go to all my friends and Laboratory technicians of the Soil Science Department for their support during Laboratory analysis of my samples.

ABSTRACT

Soil nutrient depletion in lowland rice growing ecologies in Northern Ghana is one of the major causes of low rice yields. Most nutrients applied to enhance the fertility of soil are lost through leaching due to the low CEC of the soils caused mainly by low organic matter and low colloidal clay content of the soils. The application of biochar has been found to improve soil fertility through its enhanced nutrient retention leading to increased nutrient uptake and consequently increased crop yield. The study therefore focused on assessing the potential of using rice husk biochar in combination with different sources and levels of nitrogen on productivity of a soil from lowland rice ecology. The hypothesis was that rice husk biochar in combination with inorganic or organic N will improve the growth and yield of rice and chemical properties of a typic Eutric Gleysol. Soil samples used for the study were collected from a lowland rice growing field in Walewale and some physical and chemical properties of the soil were determined before applying the soil amendments. A pot experiment involving twelve treatments were laid out in a complete randomized design with three replications. Two biochar application rates of 0 t/ha and 50 t/ha were combined factorially with three different rates of nitrogen at 0 kg/ha, 50 kg/ha and 100 kg/ha from two different sources viz, sulfate of ammonia and cowdung. Growth parameters such as weekly plant height and weekly tiller number were monitored one week after transplanting to harvesting. After harvest, the grain yield, straw yield and plant nutrient concentrations were determined. Residual soil analysis was carried out after harvest. The results of the study showed that grain and dry matter yield, N uptake and residual soil total N and C were influenced by amendment with biochar at 50 tons/ha. The combination of biochar at 50 tons per ha with inorganic nitrogen at 100 kg/ha produced the highest grain yield/pot and the highest nitrogen use efficiency (NUE).

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CHAPTER ONE

INTRODUCTION

Rice has become the second most consumed staple food in Ghana after maize and its consumption keeps increasing due to rising population, urbanization and change in consumer habits (National Rice Development Strategy, NRDS 2009; Global Agriculture Information Network, GAIN, 2010). According to Kranjac-Berisavljevic (2000), rice accounts for approximately 15% of the Gross Domestic Product (GDP) and its producing land size in Ghana totals about 45% of the total land area planted to cereals. The rice sector provides enormous employment to rural dwellers. A presentation on the National Rice Development Strategy (NRDS) for Ghana shows that the current per capita rice consumption in Ghana stands at 38 kg and this is expected to increase to 63 kg by the year 2018, leading to an aggregate demand of 1.68 million metric tons (NRDS, 2009). In spite of the increasing consumption of rice in Ghana, domestic demand for rice has not been adequately met by growth in local production, with average annual paddy and milled production of 493,000 tons and 322,000 tons respectively. The low productivity of rice has led to an importation of about 496,000 tons of milled rice in 2015 to compensate for the substantial rice yield gap (MoFA, 2015). This phenomenon has also created an opportunity for international food traders to supply rice to Ghana due to its high demand (Guisse, 2010). Current rice production in Ghana satisfied around 30 to 40 percent of the national demand with a corresponding average rice import bill of 450 million United State dollars annually (Angelucci, 2013; Kula & Dormon, 2009). Foreign exchange rate has significant impact on pricing of global rice trade due to price quoting in US dollars. The situation implies that a depreciating Ghanaian currency (cedi) relative to the US dollar, will require more Cedis for rice importation. This makes rice imports an issue of national concern for policy makers because of its impact on domestic currency and local industries (Awudu and Huffman, 2000).

Rice production in Ghana has been categorized into three ecosystems based on adaptive mechanism which is characterized by water supply namely; irrigated, upland and lowland rice farming. Lowland ecosystem of rice production is of the largest among the ecosystems is the most appropriate environment suitable for rice cultivation in Ghana and constitutes about 78% of arable land. The ecology is characterized by traditionally growing crops without structures to regulate the flow of water. There is also minimal use of fertilizers and most often indigenous crop varieties are used (MoFA, 2009). The potential for lowland rice farming is much higher compared to upland rice farming because lowland presents the possibility of cultivating rice two or more times annually in the absence of irrigation which makes it economically more valuable compared to upland rice farming. However paddy yields under lowland are usually low as a result of a declining soil productivity (Buri *et al* 1999).

Most rice farmers by way of improving the productivity of soils rely heavily on the use of inorganic fertilizers. However, the high cost of inorganic fertilizers make them unaffordable for most rice farmers to use. Alternatively, the adoption of an integrated approach that involves the use of fertilizers with other soil amendment could minimize the quantity of fertilizer used per unit area hence the cost.

In rice growing areas in Ghana, rice husk abounds but is hardly used as organic matter because of its high C: N ratio (Issaka *et al*., 2011). There are thus ‘rice huskmountains’ in almost all rice growing areas in Ghana breeding rodents. Disposing of the rice husk has been through burning openly which causes environmental pollution. Alternatively, burning the rice husk under no or limited oxygen supply condition to produce biochar could serve as valuable soil conditioner to improve upon soil productivity.

Biochar is a solid porous carbonaceous material produced by thermal combustion of organic material in an oxygen depleted atmosphere. It has physico- chemical properties that are suitable for safe and long term storage of carbon in the environment and for soil improvement (Shackley and Sohi, 2010).

Biochar use in Ghana could offer new technology for both soil fertility and crop productivity improvement as well as potential positive and quantifiable environmental benefits, such as carbon trading (Yeboah *et al*., 2009, Major *et al*., 2010; Sohi *et al.*,2010; Gaskin *et al*., 2010; Bracmort, 2010). The application of biochar in combination with organic and inorganic fertilizers on tropical soils can lead to increased crop yields due to the ability of charred material to persist in soil for long periods (Glaser *et al*., 2002; Ogawa *et al*.,2006; Woolf, 2008).

Numerous studies have also reported higher plant growth responses to the combined use of biochar with inorganic fertilizers signifying a synergistic relationship between the two soil amendments (Lehmann and Glaser, 2003). However, since the nitrogen content of biochar is low, plant nutrients must be supplied externally (Woods and Mann, 2000; Glaser and Birk, 2011). From long-term experiments, it has been also concluded that nitrogen (N) is the most essential nutrient element for rice, and usually it is the most yield-limiting nutrient in irrigated rice production around the world (Samonte *et al*., 2006). Additionally, inorganic nitrogen recovery rate within the tropics has been reported to be very low and mainly attributed to factors such as leaching (under flooded condition), untimely application of nitrogen fertilizers, method of placement, N source and soil fixation, (Nyalemegbe *et al.*, 2012).

Many sub-saharan African (SSA) farmers especially Ghanaian farmers are aware of the potential contribution of nitrogen to rice production. However, the use of nitrogen fertilizers in sub-Sahara Africa is very low compared to the world average (Woomer and Munchena, 1993). On the average, less than 5 kg/ha of inorganic fertilizer materials are applied to food crops in the sub-Sahara Africa (Tisdale *et al*., 2002). The low adoption of fertilizer has been attributed to high costs coupled with low producer price of most food crops. The constraints to inorganic fertilizer in Ghana call for investigation into the possibility of reducing the fertilizer N rates by combining the nutrient with conditioners to meet the N requirements of rice to increase yield.

1.1 Problem statement

The current national average yield of rice **is** low and is estimated to be 2.7 Mt/ha (SRID, 2014). Low inherent soil fertility and declining soil productivity as a result of continuous cultivation has been recognized as some of the main causes of low yield in rice (Buri *et al*., 2011). The continuous decline in rice yields on smallholder farmers fields has led to a huge gap between potential crop yields and actual crop yields.

Northern region is one of the regions noted for rice production under lowland ecology. Even though the region is the second highest rice producing region after Volta region, yield is low under lowland production (SRID MoFA, 2015). Rice farmers have relied on inorganic fertilizers to improve upon the fertility of soils within the region. Responses to inorganic fertilizers have been low because of low application rates. In addition, most of the nutrients especially nitrogen applied to these soils are lost through leaching due to the low CEC resulting from low input of organic matter and the inherently low clay contents of the soils. Organic fertilizers, on the hand, are very scarce in most of the rice growing areas in the Northern Region making their use limited in the rice growing communities. To achieve adequacy in rice production, hence reduction in rice imports, there is the pressing need to manage some of the soil infertility problems by adopting an integrated approach that is affordable to the rural poor farmer.

1.2 Justification

Integrated approach of soil fertility management involving the use of biochar in combination with inorganic or organic fertilizers in Ghana is new and now being assessed in the perspective of the agricultural crop production system. The addition of biochar to soil has been reported to enhance soil cation exchange capacity, soil organic carbon, plant nutrient availability and fertilizer use efficiency due to reduced nutrient losses on highly weathered infertile tropical soils (Glaser *et al*, 2002; Lehman *et al*., 2003; Liang *et al.*, 2006).

Most of the research work on biochar in Ghana has been conducted on highly weathered Ultisols and Alfisols with little to no information on the Eutric Gleysol used in lowland rice production. Additionally, the effect of using biochar in combination with organic and inorganic N fertilizer in a bid to optimize N availability too has received little attention.

In pursuance of the country's goal of decreasing rice imports and making rice production more competitive, a critical study is required to evaluate the agronomic benefit of biochar prepared from rice husk on rice production vis-à-vis inorganic and organic N fertilizer application rates if the country's quest for increased commercial rice production is to be realized. The use of rice husk biochar will additionally help to reduce CO_2 emission to the atmosphere through the otherwise aerobic burning of the material. The use of rice husk biochar in rice production, if successful, will minimize rodent infestation of rice farms and mills and will furthermore be an attempt at closing the nutrient loop in rice production.

The objectives of this study were therefore, to;

i. Determine the influence of rice husk biochar in combination with different sources and rates of N on the growth and yield of rice.
ii. Evaluate the influence of rice husk biochar on some chemical properties of a typic Eutric Gleysol after amendment for rice cultivation.
iii. Evaluate the influence of rice husk biochar on nitrogen use efficiency.

1.3 Hypothesis

H_O: Rice husk biochar in combination with inorganic and organic N will not improve the growth and yield of rice and the chemical properties of a typic Eutric Gleysol.

H_A: Rice husk biochar in combination with inorganic and organic N fertilizer as amendments will improve growth and yield of rice and chemical properties of a typic Eutric Gleysol.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Rice Taxonomy and Botany

Rice is the second most cultivated grain crop in the world after maize (Boumas, 1985). There are two species of domesticated rice in the Poaccae family namely *Oryza sativa* and *Oryza glaberrima* (Linscombe, 2006). The *Oryza sativa family* is a native of tropical and subtropical southern Asia whiles *oryza glaberrima* is a native of Southeastern Africa (Linares, 2002). *Oryza glaberrima* is less yielding compared to *Oryza sativa* but resistant to several stresses (WARDA, 1996; Jones *et al*, 1997). Although they are distinctively different from each other, *Oryza glaberrima* and *Oryza sativa* are used as the background parents in varieties amelioration programmes.

The rice crop is cultivated as a monocarpic annual grass with hairy auricle, jointed hollow round culms, flat, sessile leaf blades, and a terminal panicle. It has intercalary meristems that enable the crop grow vertically without lateral thickening and enable it survive as a perennial crop in tropical areas. It has the ability to produce ratoons and survive for about 20 years (Boumas, 1985). Depending on the crop variety and fertility status of the soil, the rice plant usually grows to 1.0 – 8 m tall producing small wind pollinated flowers in a branched arching to the pendulous inflorescence.

2.2 Rice production in Ghana.

The two main rice varieties cultivated in Ghana are *Oryza sativa and Oryza glaberima* (Agbanyo 2012). Rice is cultivated in the ten regions of the country (MiDA, 2010). The crop is grown within all the main ecological-climatic zones with the Northern, Volta and Upper East regions being the main rice producing regions in the country producing an average paddy yield of 45,000 to 160,000 tons annually (MoFA, 2015; USAID, 2009).

Rice production in Ghana is mostly dominated by smallholder farmers, with farm size below one hectare (Angelucci *et al*., 2013). Most of these small scale farmers rely on the use of low-quality seeds as planting materials for cultivation, which affects the growth pattern and results in irregular maturity time. This therefore affects harvest and rice grain quality (Angelucci *et al.*, 2013). Women perform an important role in the rice production value chain. They are mainly involved in activities such as transplanting, manual weeding, fertilizer application and scaring of birds. Also, women carry out post-harvest operations like; packaging, threshing, hauling, winnowing, drying, parboiling, milling, storage and marketing. Conversely, men predominantly carry out land preparation activities which encompass land clearing, ploughing, harrowing and also harvesting (Norman & Kebe, 2006).

In Ghana, rice is cultivated in three different ecologies which comprise; upland rain-fed, lowland rain-fed, and irrigated ecologies. Lowland rain-fed ecology accounts for approximately 78% of the country's rice production. Upland rain-fed and irrigated ecologies on the other hand produce about 6% and 16%, respectively (MoFA, 2009). Under the upland rain-fed ecology, the cultivation of rice is done on well drained soils with relatively low water table normally below the root zone of the plant. Precipitation is therefore the only source of moisture for crops in this ecology, consequently cultivation can only be done once in a year under mono-modal rainfall pattern areas (Kranjac-Berisavljevic *et al.*, 2003). Weeds-crop competition is very intense in this ecology since the soil condition is suitable for most weeds. Short duration and drought tolerant varieties are predominantly grown in this ecology. Varieties of *O. glaberrima* are commonly grown due to their tallness and ability to compete effectively with weeds (Agbanyo, 2012). These varieties are well adapted to the harsh environmental conditions, diseases, insects, pests, and the low soil fertility (MoFA, 2009).

Rain-fed lowland ecology is more suitable for rice production than the upland rain-fed ecology even though it also depends on rainfall. The soils within lowland ecology are able to retain more water during downpour due to their hydromorphic nature and the topography (Agbanyo, 2012). Generally, the field is levelled and bunded to conserve water from a downpour or other water bodies. Oteng (1997) reported that, rain-fed lowland ecology face constraints such as weed control, water management, and adverse soil conditions.

Irrigated ecology utilizes technology such as improved land preparation, improved varieties, fertilizer application and water management. As a result, it gives higher yields than the other ecologies (MOFA, 2009). The crops are not dependent on rainfall since water is frequently supplied, thus the crop can be grown for two or more times in a year. In this ecology, weed competition is rarely seen as the field is continuously submerged to control weeds.

Rice production in the country has been far lower than demand due to rapid population increase and changing consumer preferences (MiDA, 2010). This suggests that, the quantity of rice consumed in Ghana is more than the quantum produced in the country. To deal with this deficit, Ghana has to either increase its production or import rice into the country. Rice imports between 2003 and 2008 were 348,182 metric tons which accounted for 69% of the total national rice consumption needs (MiDA, 2010). Ghana produced about 30% to 40% of its rice requirement with a corresponding annual average rice import bill of USD 350 million (MOFA, 2015). The huge reliance on rice imports has been a worry for the Ghana government especially after food prices ascended in 2008. Ghana launched its National Rice Development Strategy (NRDS) in 2009 with the main objective of doubling domestic production by 2018.

2.3 Nitrogen transformation in flooded soils

Under saturated or flooded conditions, nitrification is restricted by a limited O_2 supply and NH_4^+ accumulates in the soil. At the end of a flooded rice crop, organic N and NH_4^+ N dominate and NO_3^- present is typically negligible. Subsequent drying of the soil favors aerobic N transformations. Organic N mineralizes to NH_4^+, which is rapidly nitrified into NO_3^-. As a result, NO_3^- accumulates in the soil during the aerobic phase, but is rapidly lost upon soil flooding (George *et al*., 1992). Plant growth can influence the magnitudes and forms of soil mineral N. Nitrate, the predominant form of soil mineral N during the nonflooded season, will be assimilated by plants growing during the dry season and dry-to-wet transition periods. Buresh *et al*. (1989) found that soil NO_3^- during the dry season in a lowland rice soil correlated inversely with the amount of N accumulated in weeds. Legumes grown during this season additionally accumulate atmospheric N through Biological Nitrogen Fixation (BNF). Part of the N in the plant biomass is removed from the land through the harvestable products of an economic crop. The remaining plant N can be returned to the soil as residues. Decomposition of plowed-under dry-season plant residues releases NH_4^+ into the flooded soil. Rice uptake decreases NH_4^+, the predominant N form in the flooded soil. Declining NH_4^+ level in flooded soil during the latter part of rice season is partly replenished through BNF in flooded soil (Eskew *et al*., 1981; Yoshida and Yoneyama, 1980) and from decomposition of rice roots and stubbles in addition to mineralization of soil N.

2.3.1 Soil nitrate accumulation

Nitrate-N accumulates when lowland rice soils become dry and aerated (Patrick and Wyatt, 1964, Ventura and Watanabe, 1978).

The production of NO_3^- depends on the amount of organic N available for mineralization. Organic N varies considerably in lowland rice soils, depending on the level of native organic matter, and the history of cropping and organic amendments. The amount of N mineralized is increased by higher soil organic N levels (Broadbent, 1984; Hadas *et al*., 1986; Sahrawat, 1983). Bacon (1990) reported that successive soil incorporation of rice stubble gradually increased the N mineralization potential. Residual soil water from the preceding wet season rice crop, intermittent rains, and irrigation cause fluctuating soil water conditions. Soil water fluctuation generally results in a large production of NO_3^- (Birch, 1960; Herlihy, 1979; Sahrawat, 1980; Seneviratne and Wild, 1985). In a greenhouse study, continuous soil flooding during the dry season prevented NO_3^- accumulation (Ventura and Watanabe, 1978). Drying, as well as alternate drying and wetting treatments resulted in the accumulation of soil NO_3^-. Dry-season fallows are subjected to tillage for upland crap establishment or for weed control. Tillage increases soil aeration and tends to enhance the nitrification of mineralized NH_4^+ into NO_3^- (Dowdell *et al*., 1983).

2.3.2 Loss of nitrate

Flooding of aerated soil has generally been accepted as a major factor of NO_3^- loss from rice soils (Buresh *et al*., 1989). With the use of ^{15}N microplots, Bacon *et al*. (1986) reported 90% reduction in NO_3^- concentration after flooding of a rice soil. Soil flooding can promote leaching losses of NO_3^-. Downward water flow carries NO_3^- to lower soil layers (White, 1988). Large NO_3^- losses through leaching occur generally from aggregated soils and from soils under bare fallow (Legg and Meisinger, 1982; White, 1988). These conditions exist in lowland soils during the aerobic phase before puddling for rice culture. Soil saturation depletes soil of its O_2, thus creating favorable conditions for denitrifying organisms to reduce NO_3^-.Denitrification results in the production of N_2 and N_2O (Knowles, 1982). The rates of N_2 and N_2O evolution from soils will be higher under conditions of f1uctuating redox potentials (wetting and drying cycles) than when the redox potential is continuously high (aerobic condition) or continuously low (anaerobic condition) (Letey et al., 1981; Reddy and Patrick, 1975). Mosier *et al*. (1986) measured large fluxes of N_2 and N_2O from both fallow and cropped aerobic soils following water applications. Conditions favorable for N_2 and N_2O emissions may occur during the dry-to-wet transition period in lowland rice-based crapping systems. Bacon *et al*. (1986) attributed rice soil NO_3^- loss primarily to denitrification. An incubation study with the use of ^{15}N-labeled NO_3^- by Buresh *et al*. (1989) indicated that NO_3^- completely disappeared after 9 days of flooding, and 5% or less of the added NO_3^- remained in the soil as either NH_4^+ or organic N.

2.3.3 Ammonia volatilization

Loss of nitrogen through volatilization from soils including flooded soils has been a subject of several recent comprehensive reviews. Mikkelsen *et al.* (1978) have reported the significance of NH_3 volatilization as N loss mechanism in flooded rice fields. It is clearly evident from literature that estimates of the magnitude of NH_3 volatilization loss may vary widely with the technique used for its measurement (De Datta, 1981).

The pH of the flooded water has been recognized as the single most important determinant that affect NH_3 volatilization (Jayaweera and Mikkelsen, 1990). The magnitude of NH_3 loss from submerged soils is directly related to the content of aqueous NH_3 or partial pressure of ammonia in water at the interface with the atmosphere. Aqueous NH_3 as a fraction of total ammoniacal N is directly influenced by water pH and temperature. Aqueous NH_3 is negligible below pH 7.5, but it increases rapidly from pH 7.5 to 10. At pH 9.2 about 50% of the ammoniacal N in water is present as NH_3 (Vlek and Craswell, 1981). Aqueous NH_3, at a constant ammoniacal N concentration and pH, increases linearly with temperature, resulting in nearly a fourfold increase with a change in temperature from 10 to 40°C (Vlek and Craswell, 1981).

2.4 Nitrogen (N) fertilizer management in rice paddy fields

Nitrogen fertilizer is a very important nutrient for rice growth and development. To produce 11 to 22 kg of rice grain, 1 kg of N is needed (Duxbury *et al*. 2000). Apart from being the most essential nutrient element, it has also being observed that it is the most difficult nutrient element to manage in International Irrigation (IIR) rice growing ecology. (Liu *et al.*, 2013). According to Cassman and Harwood (1995), nitrogen is extremely mobile in the soil and it is lost from the soil plant interface through different ways and this leads to low agronomic nitrogen use efficiency in rice production. However, Belder *et al*. (2005) found an increase in grain yield when nitrogen was applied at the right time in IIR system of rice production. Nitrogen deficiency during rice growth period reduces the crop biomass and increase the percentage of unfilled grains, thus reducing the grain yield (Mohammadian, 2002). Rezaei *et al*. (2009) reported that nitrogen fertilizer application increased plant height, number of panicles per meter square, harvest index and fertility percent. However, test weight, number of filled and unfilled grains and number of grains per panicle were not affected by nitrogen fertilizer application.

2.5 Importance of Nitrogen in rice plant nutrition

Among the essential nutrient elements, nitrogen is the most vital nutrient influencing the potential yield of rice (Cassman and Harwood, 1995). At early and mid tillering stage of growth, rice plants need nitrogen as much as possible for maximum panicle production. Nitrogen is also required at the reproductive and ripening stages in order to enhance number of grains/panicle and grain filling (Datta, 1986).

The amount of N removal is estimated between 16 to 17 kg for the production of one ton of rough rice (Dobermann and Fairhurst, 2000). The efficiency of nitrogen uptake ranges from 20 to 60% based on the growing ecology, pH and water temperature, doses and modes of N supply (split or blanket application) as well as varieties (Datta *et al*., 1986). Conversion of nitrogen in nitrogenous fertilizer to ammonium is essential in the nutrition of irrigated rice production (Dobermann and Fairhurst, 2000), although rice can also absorb nitrate-N (Singh *et al*. 2002).

According to Singh *et al*. (2002), ammonium-N fertilizer sources are highly recommended in submerged rice growing ecology because the NH_4^+ is stable under flooded soil conditions. The availability of excessive N in the soil does not only cause higher transpiration rates but also reduces the availability of soil water particularly during flowering and grain filling stage which contributes to reduce grain yield (Song *et al*, 2010). Under pre flooded condition, the recommended rate of nitrogen application for attainment of nitrogen uptake of 130-150 kgN/ha is 120-180 kg at panicle initiation to produce grain yield of 12 t/ha of rice per hectare (Nangia, *et al*., 2008).

2.6 Biochar

Biochar is the by-product of biomass pyrolysis in an oxygen depleted atmosphere. It contains porous carbonaceous structure and an array of functional groups (Lehmann and Joseph 2009). The product which is a mixture of various elements such as carbon, hydrogen, oxygen and in different proportions as properties which is dependent on material from which is produced and the thermal temperature (pyrolysis temperature) (Masek, 2009; Mukherjee *et al*., 2012; Zimmerman, 2012).

Biochar is progressively receiving attention in agriculture as an environmental-friendly amendment to principally mitigate climate (Lehmann and Glaser, 2003). Biochar or black carbon is rich in ‘carbon’ has a large specific surface area and has been shown to have the ability to increase water and nutrient retention of soils (Lehmann and Joseph, 2009). It also enhances the productivity of soil by improving water holding capacity, nutrients adsorption and activity of microbes and therefore increasing yield of crops. Charring of feed stocks such as sawdust, animal manure and crop residues to produce biochar helps in recycling of forestry and agricultural wastes (Lehmann *et al*., 2003).

2.7 Definition of terms

The process of biochar production is associated with a thermochemical process known as pyrolysis. Although biochar production started several years back, the science involved with its production is still poorly understood. The following list of terms have been defined to differentiate between the different terms associated with its production. These are:

2.7.1 Kiln

Kilns are equipment constructed from soil or other local materials used in the production of biochar. Modern kilns can be constructed from metals such as oil drums designed in various forms to prevent oxygen entry. The ancient and simplest way of producing char since the dawn of carbonization history is the use of earth as biochar production kilns. The use of earth as barrier in carbonization process involves underground or surface. With the underground method, a dug pit is filled with firewood and then covered with excavated soil to serve as insulator for the pit whiles the surface method involves covering a pile of wood on the ground with sand to limit air entry (Lehmann & Joseph, 2009).

2.7.2 Feedstock

Feedstock is any organic material pyrolysed to produce biochar. The physico-chemical properties of biochar produced is influenced by the type of feedstock from which biochar is produced. Organic materials such as wood waste, crop residues (including straw, nut shells, and rice hulls), switch grass, bagasse from the sugarcane industry, chicken litter are currently used as feedstocks in commercial scale or in research facilities (Das *et al*, 2008).

2.7.3 Char

Char solid component of biochar product derived from thermal decomposition of organic material. It is made up of between 60 and 90% volatile and fixed carbon. The inorganic ash component of the char is made up of different mineral compounds with approximately 6.8 g phosphorus per kg char produced from wood materials most of which are bound to char with about 15% of the phosphorus which is soluble. (Lehman and Joseph, 2009). About 1% of nitrogen is contained in the char with the rest of as gas. In the case of potassium, about 50% is accessible from the char (Pyreg, 2013)

2.7.4 Charcoal

It is solid material derived from the thermal decomposition of conversion of wood and other materials mainly used as source of fire for burning (Okimori *et al.*, 2003).

According to Harris (1999), biochar production process is similar to that of charcoal which can be considered as one of the oldest invented industrial technologies of Homo sapiens. However, biochar production can be differentiated from charcoal and other similar materials by considering the fact that biochar is synthesized completely with the intention of being applied to the soil for improving its fertility, carbon sequestration and other uses. In charcoal production, the burning of biomass in fire will create ash mainly consisting of minerals like calcium, magnesium or other inorganic carbonates in contrast to the organic carbon rich biochar. Moreover, only a limited amount of vegetation will be burnt in the conditions of limited oxygen supply, thus allowing a portion of it to remain as char.

2.7.5 Synthesis gas

This is the gaseous by-product of pyrolysis comprising a mixture of gases such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen (N_2), and hydrogen (H_2). Synthesis gas also contains methane (CH_4), water vapour, some higher hydrocarbons, various inorganic and organic contaminants like char, ash, tar, ammonia (NH_3), hydrogen sulfide (H_2S), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) (Belgiorno *et al*, 2003) . Additionally, the gas contains impurities capable of causing serious problems with downstream applications by clogging the process lines, deactivating catalysts, and acting as precursors for toxic emissions (Nordgreen *et al*, 2006). Synthesis gas can be upgraded to produce fuels such as biomethane, DME (dimethyl ether) or methanol. (Bojler Görling, 2012).

2.7.6 Biooil

The liquid part in the pyrolysis gas is called biooil and consists of long hydrocarbon chains. Biooil contains between 45% and 50% oxygen which is primarily bound in water. In the biooil more than 300 different compounds have been identified which also varies depending on the type of biomass and pyrolysis process. (Ringer *et al*., 2006)

2.8 Biochar production processes

Carbonization of wood for the purpose of biochar production is known to human from time immemorial. By utilizing waste resources, enhanced biochar technology can contribute to mankind by providing energy needs of the future and also improving soil carbon sequestration potential.

Biochar production entails heating of biomass in an oxygen deficient environment to remove volatile gases to porous carbon rich material by simple process is known as thermal decomposition usually achieved from pyrolysis or gasification (Demirbas, 2004).

The artificial production of biochar generally utilizes two methods, hydrothermal carbonization and pyrolysis. In both charring processes, organic biomass substrates (feedstock, manure, straw, etc.) are converted to carbon rich products, due to thermochemical processes under limited or no available oxygen supply (Lehmann and Joseph, 2009). Different biomass contains different fractions of fixed carbon and different amounts of lignin, cellulose and other organic compounds that will degrade at different rates and respond differently to temperatures (Bridgwater, 2012).

2.9 Hydrothermal Carbonization.

The hydrothermal carbonization of biomass is obtained by applying high pyrolytic temperature between 200 and 250 °C to a biomass in a suspension with liquid under high atmospheric pressure for several hours to produce a coal-like product called hydrochar (Funke and Ziegler 2010).

The product which is usually characterized by high carbon content and high calorific value is produced from organic materials such as municipal solid waste, wet agricultural residues, sewage sludge, algae and aquaculture residues (Afolabi *et al*, 2015). In this process, the feedstock is introduced into water under mild temperature (usually in the range 180 – 250 °C and pressure (generally autogeneous) conditions. During hydrothermal carbonization, the biomass undergoes dehydration, decarboxylation and decarbonylation reactions: the biomass is converted into a carbon-densified product hydrochar, which can be used as soil amendment to improve soil nutrient retention capacity by increasing the nutrient supply for plants and decreasing losses due to leaching (Libra *et al*, 2011).

2.9.1 Pyrolysis

Pyrolysis is the heating of organic materials at elevated temperature in an oxygen deficient environment. The products of pyrolysis are char, syngas (from synthetic gas) and bio-oil (Lehmann and Joseph, 2010; Antal and Gronli, 2003). The solid product, termed variously as char, biochar, charcoal or coke, is generally of high carbon content and may contain around half the total carbon of the original organic matter. The syngas, is the gaseous product and comprises a mixture of carbon monoxide, hydrogen and carbon dioxide can be recirculated into the pyrolyzer as a fluidizing gas or burned to provide energy for the pyrolysis process (Bojler Görling, 2012). Liquid products from biomass pyrolysis are frequently termed bio-oil.

Pyrolysis can be divided into 5 categories depending on the operating conditions used i.e. temperature, residence time, heating rate and flow rate of sweeping gas. They include slow pyrolysis, fast pyrolysis, gasification and carbonization.

2.9.1.1 Slow pyrolysis

This involves the slow heating of large biomass to temperatures in excess of 400 °C in an oxygen deficient environment to produce biochar. The residence time for feedstock in reaction is longer due to the relatively slow pyrolysis process resulting from slow transfer of heat. It yields more biochar than any other technology involved. It can preserve up to 50% of the carbon in the charred organic material (Garcia-Perez *et al.*, 2011).

2.9.1.2 Fast pyrolysis

This involves the rapid heating of biomass within few seconds or less at temperature range of 400 - 700 °C in an oxygen deficient environment. Fast pyrolysis which produces 60 to 70% of the biomass as bio oil and 15 to 25 % as biochar requires the particle size of feedstock to be generally less than 2 mm to attain the rapid heating rate (Cummer and Brown, 2002; Czernik and Brigwater, 2004; Mohan *et al*., 2006) .

2.9.1.3 Gasification

The term gasification involves the thermo-chemical conversion of biomass at high temperatures (>700 °C) under limited amount of oxygen conditions to produce combustible gases known as syngas. The main constituents of the gases include carbon monoxide (CO), hydrogen (H_2) and traces of methane (CH_4). The production of syngas by gasification is more efficient than the direct combustion of the original fuel due its combustion at higher temperatures. In addition, corrosive elements like chloride and potassium are removed during gasification due to high-temperature, which results in the production of clean gas instead of problematic fuels (Higman and Burgt 2008).

2.9.1.4 Carbonization

This process involves the conversion of biomass into carbon rich material. It represents various pyrolytic processes, similar to traditional process used for charcoal production. The temperature ranges from 280 °C to 500 °C. The biomass spontaneously breaks down and produces charcoal along with the production of some combustible and non-combustible gases (Walter 1985).

2.9.2 Structural composition of biochar

Biochar is made up of stable carbon compounds formed by heating biomass is to temperatures between 300 to 1000 °C under limited oxygen concentrations. Feedstock type from which biochar is produced and pyrolysis condition influence the structural and chemical composition of the biochar (Sohi *et al*., 2009). The proportion of aromatic carbon in biochar increases with increase in charring temperature due to the relative increase in the loss of volatile matter. As charing begins, there is evaporation of water followed by hydrocarbons, tarry vapour, H_2, CO and CO_2. Subsequently, there is conversion of alkyl and O-alkyl and C to aryl C (Baldock and Smernik, 2002; Demribas, 2004: Darko, 2013). Around 330 °C, poly-aromatic graphene sheets begin to grow laterally, at the expense of armophous carbon phase, and eventually coalesce. Above 600 °C, carbonization which is removal of most carbon atoms becomes the dorminant process and consequent relative increase of the carbon content. Carbonisation can be made up to 90% by weight in biochars from woody feedstocks (Antal and Gronli, 2003; Demribas, 2004).

2.9.3 Properties of biochar

Physicochemical properties of biochar mostly depend on two factors. They are, properties of feedstock used for production and final temperature. Depending on the starting material and process parameters (temperature, residence time, etc.), the biochar will obtain different physical and chemical structures that can modify the physical and chemical characteristics of the soil

2.9.3.1 Physical properties of biochar

The biochar structure is amorphous, containing local crystalline structures of joint aromatic compounds (Graber *et al*., 2011). The carbon skeleton formed during pyrolysis of organic matter results in a high porosity of biochar, due to its sponge-like structure (Kumari *et al*., 2014). The voids are formed as pores present as macro- (>50 µm), meso- (2-50 µm) and micropores (<2 µm). The large proportions of micropores ($<2 \times 10^{-3}$ µm in diameter) is responsible for the increasing surface area, that can reduce the mobility of soil water (Lehmann and Joseph, 2009). The high porosity results in a low bulk density, which when incorporated into the soil in sufficient concentrations can reduce the total bulk density of the soil (Laird *et al*., 2010). Most biochar exhibits a large surface area, depending on the base material and treatment. For biochar obtained from pyrolysis, surface areas range from 20 m^2g^{-1} (Chen *et al*., 2008) up to 3000 m^2g^{-1} (Guo *et al*., 2002). The large surface area of biochar will increase the ion exchange capacity and the sorption of nutrients (Lehmann and Joseph, 2009). The amount of adsorbed water is directly dependent on the surface area, therefore biochars are able to adsorb large amounts of water. The process of water adsorption on the surface area of biochar is governed by the functional groups (Antal and Grønli, 2003).

When added to the soil, biochar will increase the total soil surface area, which is one physical property that is believed to be responsible to overcome the problem of too much water held in clay soils, due to increased soil aeration, and increase the water content/water holding capacity in sandy soils (Lehmann and Joseph, 2009).

2.9.3.2 Chemical properties of biochar

The chemistry of biochar is highly dependent on the biomass used, temperature during pyrolysis and residence time. However, all biochars are composed of condensed aromatic ring structures that become larger and even more condensed with increasing pyrolysis temperature.

It is known that a range of functional groups exists on the surface of biochar, such as heteroatoms (hydrogen, oxygen, nitrate, phosphorus and sulfur), acidic carboxyl groups and other basic functional groups (chromenes and pyrenes) (Lehmann and Joseph, 2009). However, the presence of functional groups on the surface of biochar depends on the type of feedstock. Moreover, the overall assumption is that temperatures above 600 °C will decompose the functional groups through heat degradation (Jindo *et al*., 2014).

Most biochars have a strong surface area charge and thereby a high cation exchange capacity (CEC) having both cation and anion exchange capacity (Gai *et al*., 2014). Mukherjee *et al*. (2011) stated that the surface properties of biochar lead to its potentially useful properties, such as contaminant control and the release and retention of nutrients. There is small variability for the pH between biochars, with typical values above seven (Verheijen *et al*., 2010).

2.9.4 Effects of feedstock on biochar properties

Physical and chemical characteristics of biochar produced from various feedstocks vary from one another. The feedstock from which biochar is produced has effect on the chemical structure, yield and elemental compounds present in the biochar (Zhang *et al.*, 2014). The feedstock type of biochar influences the variability and contents of elemental constituents of ash in biochar (Antal and Gronli, 2003). Lignocellulosic feedstocks yield high biochar and low yield of poor quality bio-oil, cellulose-rich feedstock tends to give low molecular weight organic acids, water and pyrolytic sugar rich bio-oils whiles feedstocks high in lignin gives higher energy bio-oil enriched with mono and oligo-phenols (Laird *et al.*,2011)

Due to the loss of Carbon, hydrogen and Oxygen much of the mineral constituents of the feedstock are retained in the biochar produced (Amonette and Joseph, 2009). Concentrations of bases in biochar depend primarily on the mineral content of the biomass feedstock and will determine its credits for nutrients such as P, K^+, Ca^{2+}, and Mg^{2+} that may be given for agricultural applications of biochar (Laird *et al.*, 2009). The elemental contents of biochar especially N and P vary considerably due to the characteristics of feedstock. Feedstocks such as animal manures, biosolids and sewage sludge have high contents of nitrogen, phosphorous, potassium and Sulphur. There has been reported decrease of 60 to 80% of nitrogen in biochars derived from sugarcane bagasse, sewage sludge, rice husk and cattle manure (Shinogi and Kanri, 2003).

Sohi *et al*. (2010) reported that the difference in magnitudes of surface area, pores and functional groups in biochar as a result of the difference in the feedstock, and how it affects the sorption characteristics of biochar. Biochar produced from manure-based feedstock has a higher CEC than that of wood based feedstock (Singh *et al.*, 2010), but the wood-based biochar has a higher saturated hydraulic conductivity (Lei and Zhang, 2013). Wood-based feedstocks produce biochar that are coarser and more resistant (Winsley, 2007).

The pH of biochar is also affected by the feedstock type with wood-based biochar having high pH and stable carbon than manure and crop residue based biochar (Novak *et al.*, 2013; Brewer and Brown, 2012).

2.9.5 Effects of temperature on biochar properties

Biochars produced from the same feedstocks may not possess similar properties due to differences in production conditions such as pyrolysis temperature and more specifically the final combustion temperature. The structural and physicochemical properties of biochar, pore structures, such as surface area, surface functional groups and elemental composition, can also be affected by varying the pyrolysis condition, such as pyrolysis temperature, heating rate and residence time (Tang *et al*., 2013; Brewer *et al*., 2009)

Various studies have indicated that there is a decrease in biochar yield with increase in pyrolysis temperature (DeSisto *et al*. 2010; Garcia-Perez *et al*. 2008; Keiluweit *et al*. 2010). The decrease in biochar yield is as a result of combustion of organic materials as well as depolymerization of cellulose and hemicellulose (Demirbas 2004; Cao and Harris 2010). According to Muradov *et al.* (2012), the decrease in biochar yield with increased charring temperature is due to increase in the rate of volatilization of organic compounds.

The main factor governing the surface area of biochar is pyrolysis temperature. Day *et al*., (2005) reported an increase in surface area of biochar from 120 to 460 m^2/g following an increasee in charring temperature from 400 to 900 °C. Biochar produced under low temperature regimes may be suitable for regulating the release of nutrients contained in feedstock whiles biochar produced under high temperature regimes result in formation of materials similar to activated carbon (Ogawa *et al*., 2006). Additionally, the surfaces of biochar produced under low temperature conditions can be hydrophobic thereby limiting their ability to water storage within soil. Biochar produced under lower charring temperature contains volatile compounds that can seal pore spaces leading to lower biochar surface area. The pore sealing effect is however reduced under high temperature condition (>650 °C) as there is burning of volatile matter at higher charring temperatures (Mukherjee *et al*., 2011). There is accessibility of surface pore spaces of biochar at temperatures between 650 and 750 ℃ due to volatilization of liquid components of biochar. Howerever, there is collapse in the micropore structure of biochar when temperature rises above 750 ℃ leading to decrease in surface area of biochar (Lua and Guo , 1998).

The chemical properties of biochar are also greatly affected by temperature and heating rate. Angin (2013) reported an increase pH values of biochar following increased pyrolysis or charring temperature. Yuan *et al*. (2011) attributed the increase in pH values to the separation of basic salts from organic materials due to increase in pyrolysis temperature.

The quantity of carbon in biochar increases with increase in charring temperature, while the oxygen and hydrogen content decrease with respect to carbon content (Chen *et al*. 2011; Chun *et al*. 2004). In addition, increasing the charring temperature lead to an increase the ash and fixed C contents, and to a decrease the content of volatile materials (Tag *et al*, 2016). Furthermore, the H/C and O/C ratios of biochar are affected by charring temperature with the ratios of H/C and O/C decreased with increasing temperature. Other properties such as porosity, surface area, surface functional groups and cation exchange capacity (CEC) of biochars (Sun *et al*, 2014). According to Lehmann (2007) the Cation Exchange Capacity (CEC) of biochar increases with increased charring temperature. Lakaria *et al* 2012, observed differences in nutrient composition of biochars made under varying pyrolytic temperature and duration. There is decrease in the volatile and Nitrogen component of biochar whiles an increase in ash and fixed carbon content following an increase in pyrolysis temperature from 400 ℃ to 600 ℃

2.9.6 Nitrogen fertilizer and biochar interaction

Biochar directly and indirectly alters plant nutrient availability in soil. There is an increasing evidence suggesting that biochar impacts a number of soil N reactions (Clough *et al*., 2013) and the effects is dependent on biochar feedstock and production condition, in addition to soil properties and environmental conditions.

Biochar has been observed to affect N fixation (Mia *et al*. 2014), N mineralization or immobilization (Ameloot *et al*., 2015), increase or decrease nitrification (Ulyett *et al*., 2014), denitrification (Cayuela *et al*., 2013), or ammonia volatilization (Mandal *et al*., 2016). Biochar also alters nodulation by N-fixing bacteria in crops such as pea, soybean and red clover, leading to increased plant biomass production, in association with increased B and Mo concentrations in biochar-amended soils (Mia *et al*., 2014; Ogawa and Okimori 2010; Rondon *et al*., 2007). Rondon *et al*. (2007) evaluated the biological N_2 fixation by common beans (Phaseolus vulgaris L.) through biochar additions and reported that proportion of fixed N by Rhizobium strains increased by 72% when 90 g biochar per kg of soil soil was added. Bean yield was also increased by 46% with 90 g biochar kg^{-1} soil in comparison to no biochar treatment.

A stimulation of N mineralization has been observed as a consequence of labile C addition or a result of soil pH neutralization linked to the stimulation of microbial activity and abundance. Biochar-induced changes in N cycling differ substantially from potential lime-induced changes, as biochar may sorb NO_3^- , NH_3, NH_4^+ and organic-N (Bai *et al*., 2015) as well as compounds such as phenolics that could otherwise inhibit nitrification (DeLuca *et al*., 2006). In addition, indirect mechanisms associated with soil microbial composition changes can be generated by the specific properties of biochar and thereby have strong implications for soil microbial N processing. Nitrification rates were accelerated by addition of biochar in two acidic arable soils (Zhao *et al*., 2014). He *et al*. (2016) also reported an increased nitrification activity in biochar-amended acid oxisol when exogenous NH_4^+ was added, suggesting that nitrification, after successive biochar applications, was not limited by nitrifier activity as was observed in unamended soils.

Biochar is more resistant when applied to the soil. Upon addition of biochar to the soil, there is enhacement of nitrogen utilization from applied chemical fertilizer (Steiner *et al*., 2007 ; Widowati *et al*.,2011). The reduction in nitrogen loss is as a result of increased cation exchange capacity of soil following biochar addition (Chang *et al*., 2008; Masuilli *et al*., 2010).

Biochar amendments in temperate soils have the potential to recover N from high nutrient waste products (e.g. sewage sludge, poultry litter, food waste) (Bridle and Pritchard, 2004). Direct fertilization occurs when a high nutrient biochar is added to soil, leading to increased nitrogen uptake by plants (Chan *et al*., 2008). Low-ash biochars indirectly improve nutrient retention in soils, for plant nutrients such as NH_4^+, NO_3^-, K^+, Ca^{2+}, Mg^{2+}, Zn^{2+} and Cu^{2+}, by increasing soil CEC (Gaskin *et al.,* 2010; Kameyama *et al*., 2012; Major 2009; Van Zwieten *et al*., 2010).

Many studies have reported that biochar incorporation could reduce inorganic N leaching and increase N retention in the soil (Major *et al.*, 2012; Sun *et al*., 2017; Yao *et al*., 2012). The mechanisms underpinning the effects of biochar on N retention in soil are not well understood, but some potential processes have been proposed: a). Biochar has a high cation exchange capacity (CEC) (Ding *et al*., 2010; Nelissen *et al*., 2012) and changes the soil pH (Novak *et al*., 2009), leading to the direct absorption of NH_4^+ and NO_3^-. b). Biochar can enhance the water-holding capacity (WHC) of the soil and thus reduce the total volume of leachate (Ouyang *et al*., 2013; Zheng *et al*., 2013). c). Due to microbial immobilization (Ippolito *et al*., 2012), biochar, especially when pyrolyzed at low temperatures, usually contains considerable amounts of labile carbon (Nelissen *et al*., 2012). This carbon can serve as a microbial substrate, resulting in microbial demand for inorganic N, which thereby immobilizes the N through biotic processes (Lehmann *et al*., 2003 Nelissen *et al*. 2012 and 2014; Zheng *et al*. 2013). Ammonia volatilization is another mechanism that accounts for the loss of fertilizer derived N. This process tends to increase following the addition of biochar (Reverchon *et al*., 2014; Yang *et al*., 2015) because most biochars have a high pH and serve as liming agents (Novak *et al*., 2009). Even though previous studies have focus on using biochar to improve soil fertility, there is limited information on how biochar interact with nitrogen sources under flooded conditions.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Soils and sampling

The soil was sampled from the savanna zone in the Northern Region of Ghana. The area has an average annual rainfall of about 870 mm (MoFA, 2015). The soil used for the experiment is the Lima series classified as Eutric Gleysol by the Soil Research Institute (1990) according to the FAO/UNESCO classification system (1990). The soil was located at 10º28’29.0”N and 0º47’55.5”W. Soil samples used for the pot experiment were randomly taken from the plough layer (0 – 20 cm), bulked, homogenized and sub samples taken for routine characterization and pot experiment. Undisturbed samples were also taken for bulk density determination. The disturbed samples were air-dried and portions were ground to pass through a 2 mm sieve to obtain the fine earth fraction. The remaining soil was not processed (whole soil) and was used for pot experiment in a screen house.

3.2 Soil characterization

3.2.1 Physical analyses

The soil physical properties that were determined included bulk density and particle size distribution.

3.2.1.1 Bulk density determination

The surface of the soil from which the soil was to be sampled was cleared by removal of plant debris and a 2.5 centimeter radius core sampler of known height was driven into the soil. To avoid compaction, another core sampler of known length was placed on the core sampler in the soil and hit with a hammer until the other in the soil was completely buried. The buried core sampler was then carefully removed and extraneous soil around the core sampler was removed. The process was repeated three times to obtain three replicate for the soil sample. The samplers were trimmed of soil at the ends after which each soil in the sampler was placed into a moisture can for drying at 105 ºC in an oven for 24 hrs. The oven dry mass of each soil in the core sampler was then recorded. The volume of the core sampler was determined from its radius and height. The field bulk density of the soil was calculated as follows;

$$\rho_{b\,(kg/m^3)} = \frac{M}{(\pi d^2/4)h} \qquad \text{..[3.1]}$$

Where

ρ_b= Bulk density of soil

M= mass of soil = W_2-W_1

W_2 = Weight in gram taken after oven drying the moisture can and its contents.

W_1 = Weight in gram of empty moisture can.

π d2/4= area of core base

d= diameter of core

h= height of core

(π d2/4) h= volume of core (i.e. volume of soil)

3.2.1.2 Particle Size Analysis

Bouyoucos hydrometer method modified by Day (1965) was used to determine the particles size distribution of the soil samples. Forty grammes (40 g) of the fine earth was weighed into a dispersing bottle. The soil was treated with H_2O_2 (1:1 soil: solution) to destroy the organic matter after which 100 mL of 5% calgon (sodium hexametaphosphate) solution was added to form a suspension. The suspension was shaken on a reciprocating mechanical shaker for 2 hours to help disperse the soil into the various separates (sand, silt and clay). The suspension of was then transferred into a 1 L graduated sedimentation cylinder and distilled water added to reach the 1 L mark.

A plunger was used to vigorously agitate the soil suspension and then allowed to stand. After five minutes, a hydrometer was immersed and the first hydrometer reading taken. The first hydrometer reading was for both silt and clay in suspension. The second hydrometer reading (density of clay only in suspension) was recorded after 5 hours. The suspension was directly transferred onto a 47 µm sieve to determine the quantity of sand in the mixture. The content on the sieve was washed thoroughly with tap water to get rid of any clay and silt particles and then transferred into a moisture can of known weight for oven drying at 105 ºC for 24 hours. The hydrometer readings at five minutes and five hours were also taken for the blank which contained 5% calgon only.

A thermometer was used to record temperatures of the suspensions at both hydrometer readings and the readings were recorded. Temperature effects on density of the soil particles were accounted for by using the relation provided by Day (1965). For every 1°C increase in temperature, above 19.5 °C, there is an increase of 0.3 in the density of the particles in suspension.

Correction for temperature = blank hydrometer reading – increase in weight of soil particles

The concentration of the three separates were calculated as follows:

$$\%\ \text{clay} = \frac{\text{hydrometer reading at 5 hrs}}{40\ \text{g}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [\ 3.2\ ]$$

$$\%\ \text{silt} = \frac{\text{hydrometer reading at 5 min} - \text{hydrometer reading at 5hrs}}{40\ \text{g}} \times 100 \ldots\ldots\ldots\ldots [3.3\ ]$$

$$\% \text{ sand} = \frac{\text{weight of oven dried sample}}{40 \text{ g}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.4\ ]$$

Where 40 = weight of soil sample in grams

The particle size distribution values calculated were used to determine the textural class of the soils with the aid of the USDA textural triangle presented in the appendix.

3.2.2 Chemical analyses of soil

3.2.2.1 Soil pH

The pH of the soil in water was determined by weighing twenty grams of soil into a beaker followed by addition of 20 mL of distilled water to obtain soil to water ratio of (1:1). This ratio was used to ensure enough volume of supernatant for immersion of electrode. The mixture was then stirred several times for about 30 minutes and allowed to stand for about an hour to enable most of the suspension to settle and also for the temperature of the suspension to equilibrate with the room temperature. The glass electrode pH meter (pH-mV-Temp PL-700PV) was standardized using two solutions of pH 4 and 7. The electrode was rinsed with distilled water and then immersed into the partly settled suspension and the reading on the pH meter recorded. The determination of pH of the samples was repeated using 1 M KCl solution according to the protocol outlined.

3.2.2.2 Total carbon and Total nitrogen

The total carbon and nitrogen contents of the soils were determined using a Leco Trumac Carbon Nitrogen Sulphur version 1.3 Analyzer. Two hundred milligrams of the fine earth fraction of each soil was weighed into platinum crucibles and each mixed with 500 mg of comcat and placed in the furnace of the analyzer. The C and N concentrations in the samples were read after 6 minutes of combustion.

3.2.2.3 Exchangeable bases and Cation Exchange Capacity

Ten grams (10 g) of the soil samples (2 mm sieved) were weighed into a 200 mL extraction bottles. Hundred (100 mL) of 1N ammonium acetate (NH_4OAc) solution buffered at pH 7.0 was added. The bottles were covered with lid and then placed on a reciprocating shaker and shaken for 1 hr at 180 strokes per min. The soil suspension was then filtered through a No. 42 Whatman filter paper. The filtrates were used for the determination of Ca, Mg, K and Na.

A 5 mL aliquot of the filtrates from section 3.2.2.3 was pipetted into 50 mL volumetric flask and deionized water added to reach the mark on the volumetric flask. The Perkin Elmer atomic absorption spectrometer (Analyst 800) was calibrated with the appropriate standards for Ca, Mg and Na respectively and the absorbance for each element determined. Exchangeable Na and K were calculated as:

$$\mathrm{Ca}\ (\mathrm{cmol_c kg^{-1}}) = \frac{\mathrm{R} \times \mathrm{Vol.of\ extract} \times 10^{3}(\mathrm{g}) \times 10^{2}(\mathrm{cmol}) \times \mathrm{E}}{\mathrm{Weight\ of\ soil} \times 10^{6}(\mu\mathrm{g}) \times 40} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.5]$$

Where 40 = Atomic mass of Ca and

R = AAS (Atomic absorption spectroscopy) reading in mgL^{-1}

E = Charge of Ca

$$\mathrm{Mg}\ (\mathrm{cmol_c kg^{-1}}) = \frac{\mathrm{R} \times \mathrm{Vol.of\ extract} \times 10^{3}(\mathrm{g}) \times 10^{2}(\mathrm{cmol}) \times \mathrm{E}}{\mathrm{Weight\ of\ soil} \times 10^{6}(\mu\mathrm{g}) \times 24} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.6]$$

Where 24 = Atomic mass of Mg

R = AAS (Atomic absorption spectroscopy) reading in mgL^{-1}

E = Charge of Mg

$$\text{Na}\ (\text{cmol}_c\text{kg}^{-1}) = \frac{\text{R} \times \text{ Vol.of extract} \times 10^3(\text{g}) \times 10^2(\text{cmol}) \times \text{E}}{\text{Weight of soil} \times 10^6\ (\mu\text{g}) \times 23} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[3.7]$$

Where,

R = AAS (Atomic absorption spectroscopy) reading on mgL^{-1}

23 = Atomic weight of Na

E = Charge of Na

The K content in the diluted soil extracts from section 3.2.2.3 were measured with the standardized flame photometer. The flame photometer was standardized to give a 100 full scale deflection at 10 mg/kg of K. The values obtained were then used to calculate the amount of potassium contained in the soils as shown in the formula below:

$$\text{K}\ (\text{cmol}_c\text{kg}^{-1}) = \frac{\text{R} \times \text{ Vol.of extract} \times 10^3(\text{g}) \times 10^2(\text{cmol}) \times \text{E}}{\text{Weight of soil} \times 10^6(\mu\text{g}) \times 39.1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[3.8]$$

Where,

R is the flame photometer reading (ppm)

39.1 = Atomic weight of K

E = Charge of K

3.2.2.4 Cation Exchange Capacity (CEC)

The soil residues after filtration in section (3.2.2.3) was immediately leached with 50 mL portions of methanol into empty plastic bottles. The soils were leached again with 50 mL portions of acidified 1M KCl through a No. 42 Whatman filter paper into different plastic bottles. Each portion was added at a time and allowed to pass through, before adding the next portion. Ten millilitres (10 mL) of the leachates were then transferred into a Kjeldahl flask and 5 mL of 40% NaOH was added and distilled. The distillate was collected in 5 mL of 2% boric acid in a conical flask to about 30 mL and then back titrated against 0.01M HCl to determine the ammonium ion concentration. The CEC of the soil was estimated after determination of ammonium ion concentration in the filtrate.

3.2.2.5 Exchangeable Acidity (H^+ and Al^{3+}).

Five (5) grammes of soil was weighed into a 100 mL extraction bottle and 50 mL of 1 M KCl solution was added. The bottle and its content were placed on a mechanical shaker and shaken for 1 hour. The soil suspension was then centrifuged and the supernatant decanted into an empty clean bottle. With the aid of a pipette, twenty millilitres (20 mL) aliquot was taken and transferred into a 100 mL conical flask, heated to near boiling point to drive out CO_2, allowed to cool down and 2-3 drops of phenolphthalein indicator added for titration to a permanent pink end point against 0.01 M NaOH. The titre value was recorded as titre for both H^+ and Al^{3+}. Five millilitres of 4% NaF was added to the solution at the endpoint and back titrated against 0.01M HCl until a colourless end point was reached. The titre value was recorded as that for Al^{3+}.

$$\text{cmol}_c\text{/kg KCl acidity} = \frac{(mL\ NaOH\ sample - mLNaOH\ blank) x N x 100}{sample.g} \ldots\ldots [3.9]$$

$$\text{cmol}_c\text{/kgKCl exchangeable Al} = \frac{ml\ HClxNx100}{sample.g} \ldots\ldots [3.10]$$

$$\text{cmol}_c\text{/kgH} = \text{KCl exchangeable acidity} - \text{KCl exchangeable Al} \ldots\ldots [3.11]$$

3.2.2.6 Effective Cation Exchange Capacity (ECEC)

The Effective Cation Exchange Capacity is obtained by summing up the exchangeable Ca^{2+}, Mg^{2+}, Na^+, K^+, H^+, and Al^{3+}. (i.e. Ca^{2+}+ Mg^{2+}+ Na^++ K^++ H^++Al^{3+})

3.2.2.7 Available Phosphorus

The available phosphorus in the soil samples were determined using the method of Bray and Kurtz, (1945). Fifty millilitres of Bray 1 solution (0.03 M NH_4F in 0.025 M HCl) was added to five grams (5g) of soil in an extraction bottle. The soil suspension was shaken for 3 min on a reciprocating shaker at 180 strokes per min, allowed to settle and the supernatant was filtered into a 100 mL volumetric flask through a No. 42 Whatman filter paper then distilled water added to reach the mark. Phosphorus in the filtrate was determined using the Murphy and Rilley method (1962) molybdate blue-ascorbic acid colour development method as follows:

A solution of 12 g of ammonium molybdate and 0.2998 g of antimony potassium tartrate dissolved in 250 mL of distilled water was prepared and added to 1000 mL of 2.5 M H_2SO4 mixed thoroughly and made to volume in a 2 L volumetric flask and labelled Reagent A. Another solution was prepared by dissolving 1.056 g of ascorbic acid in 200 mL of Reagent A and labelled as Reagent B.

Five millilitre (5 mL) aliquots of the filtrates were pipetted in duplicate into a 50 mL volumetric flask and the pH adjusted with *p*-nitrophenol indicator. The solution was then neutralized with a few drops of ammonium hydroxide (4M NH_4OH) until the colour changed to yellow. Eight millilitres (8 mL) of Reagent B was then added to the sample solution and made to volume in a 50 mL volumetric flask. A blank was also prepared using 5 mL of distilled water and 8 mL of reagent B. The Spectroquant® Pharo 300 M spectrophotometer was calibrated using 5, 10, 15, 20, 25 and 30 mg L^{-1} standard P solutions prepared in the same manner as above. Phosphorus in the solution was determined by reading the resultant colour intensity on the Spectroquant® Pharo 300 jM spectrophotometer, at a wavelength of 712 nm. The available P concentration in the soil sample was read and calculated using the spectrophotometer reading as follows

$$\text{P (mg/kg)} = \frac{\text{spectrophotometer reading } (mgL^{-1}) \times \text{volume of extract}}{\text{volume of aliquot} \times \text{weight of soil sample} \times 10^{6}} \times 100 \ldots\ldots\ldots\ldots\ldots[3.12]$$

3.2.2.8 Total Phosphorus

Total phosphorus was determined by digesting 2 g of 0.5 mm sieved soil with 25 mL of a mixture of concentrated HNO_3 and 60% $HClO_4$ in a ratio of 2:3 (HNO_3 : $HClO_4$). The digestion was continued until white fumes of $HClO_4$- ceased. The digest was cooled, diluted with distilled water and then filtered into a 100 mL volumetric flask using a No. 42 Whatman filter paper. The volume was brought to the 100 mL mark with distilled water. The total phosphorus in the filtrate was measured by colour development and read on Philips PU 8620 spectrophotometer as described in section above (3.2.2.7) and the determination of P in soil sample was calculated using equation below

$$\text{P (mg/kg)} = \frac{\text{spectrophotometer reading } (mgL^{-1}) \times \text{volume of extract}}{\text{volume of aliquot} \times \text{weight of soil sample}} \ldots\ldots\ldots\ldots\ldots\ldots [3.13]$$

3.3 Rice husk characterization

Rice husk was collected from a rice processing mill at the Irrigation Development Authority at Ashaiman in the Greater Accra Region of Ghana. The feedstock was air-dried, milled to pass through a 0.5 mm sieve and saved for chemical analysis.

3.3.1 pH in water and KCl

One gram of rice husk was weighed into a beaker and 20 mL of distilled water added, to give rice husk water ratio of (1:20). This ratio was used to allow enough volume of supernatant for immersion of electrode. After continuous stirring for 30 minutes, the mixture was allowed to stand for an hour to allow the suspension to settle and the suspension temperature to equilibriate with the temperature of the room. The glass electrode pH meter- CG818, Schott Great was standardized using two solutions of pH 4 and 7. The electrode was rinsed with distilled water and then dipped into the partly settled suspension and the reading on the pH meter taken. The determination of pH of the samples was repeated using 1 M KCl solution according to the protocol outlined.

3.3.2 Total carbon and Total nitrogen of rice husk

The total carbon and nitrogen content of the rice husk were determined using a Leco Trumac Carbon Nitrogen Sulphur version 1.3 Analyzer. Two hundred milligrammes of the rice husk was weighed into platinum crucibles and each mixed with 500 mg of comcat and placed in the furnace of the analyzer. The total N and C concentration in the samples were read after 6 minutes of combustion.

3.4 Biochar preparation and processing

The biochar was produced using locally fabricated conically shaped metal called the Kuntan Kiln (plate 1). The process involved placing the kiln on a flat cemented platform as shown below. The flame was then set up within the kiln using pieces of dried grasses and wood. The flame provided energy for the pyrolysis. When the flame finally lit up, the feedstock (rice husk) was gathered around the base of the kiln.

Plate 1 Locally manufactured kuntan kiln

Plate 2 Rice husk feedstock under charring

The charring process started 10 to 15 minutes later when the rice husk feedstock started browning at the neck. The feedstock was turned thereafter every ten to fifteen minutes to obtain uniformly charred material and minimize the production of ash. During the charring process, a dual laser infrared thermometer was pointed to the heap to note the charring temperature which was between 537.2 °C and 628.1 °C. The charring lasted between 40 to 50 minutes.

Plate 3 Partially charred rice husk biochar

Plate 4 Completely charred rice husk

The biochar was then spread evenly on the cemented platform at the end of charring and water sprinkled on it to put off the fire and to end the charring process. The biochar was then rinsed with distilled water several times to get rid of the ash and then air dried.

The biochar yield from charring of rice husk feed stock was estimated as follows

$$Biochar\ yield(By) = \frac{Dry\ weight\ of\ biochar(DB)}{Dry\ matter\ weight\ of\ feedstock(DF)} \times 100\% \text{ ……………….……….. [3.14]}$$

The biochar was then grounded to pass through a 2 mm sieve and saved for routine chemical analyses

Plate 5 Water being sprinkled on biochar to put off fire and to end up charring process.

3.5 Biochar characterization

Samples of the prepared biochar was taken to the laboratory after air drying and sieving through a 2 mm sieve for analysis to determine some chemical properties.

3.5.1 Biochar pH

Two grams (2 g) of biochar was weighed in triplicate into 50 mL beakers and 20 mL of deionized water was added to give a biochar to water ratio of 1: 10. The suspension was stirred continuously for 30 min, left to stand for 1 hour to equilibrate with room temperature. The glass electrode pH meter (pH-mV-Temp PL-700PV) was standardized using pH solutions of 4 and 7. The electrode was dipped into partly settled suspension of biochar and the reading on the pH meter taken. The same procedure was used to determine the pH of the biochar in 1 M KCl.

3.5.2 Biochar Total Nitrogen and Total Carbon

The total carbon and nitrogen content of the biochar were determined using a Leco Trumac Carbon Nitrogen Sulphur version 1.3 Analyzer. Two hundred milligrammes of the rice husk biochar was weighed into platinum crucibles and each mixed with 500 mg of comcat and placed in the furnace of the analyzer. The total N and C concentrations in the samples were read after 6 minutes of combustion.

3.5.3 Biochar Total Phosphorus

Total phosphorus was determined by digesting 0.2 g of biochar with 25 mL of a mixture of concentrated HNO_3 and 60% $HClO_4$ in the ratio of 1:1.5 (HNO_3: 60% $HClO_4$). Distilled water was added to the digest, filtered and made up to volume in a 100 mL volumetric flask with distilled water. The total Phosphorus in the digest was determined as described by the Murphy and Rilley method (1962) method as outlined earlier in section (3.2.2.7). The P content of the samples in triplicates was then read with the spectrophotometer, and the calculations were done as follows:

$$\text{Total P (\%)} = \frac{\text{spectrophotometer reading } (mgL^{-1}) \times \text{volume of extract}}{\text{volume of aliquot} \times \text{weight of biochar}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots[3.13]$$

3.5.4 Biochar Available Phosphorus

Fifty milliliters (50 mL) of 0.5 M $NaHCO_3$ solution was added to one gramme of biochar contained in an extraction bottle and mixture shaken for thirty minutes on a mechanical shaker. The biochar extractant mixture was filtered through a Whatman No. 42 filter paper. A 10 mL aliquot was taken and 10 mL sulphuric acid (H_2SO_4) added and centrifuged at 3000 rpm for 15 minutes. The concentration of the P in each sample was then determined after colour development using the Murphy and Rilley method (1962) method as described in section (3.2.2.7). The intensity of the colour developed at a wavelength of 712 nm was read on the UV spectrophotometer and recorded. The P was then calculated as in equation [3.13] above.

3.6 Screen house studies

Pot experiment was conducted in a screen house at the “Sinas Garden” of University of Ghana, Legon. Temperature in the screen house throughout the experiment was between 25 ^{o}C and 32 ^{o}C The potted plants were put in a screen house to control environmental conditions.

3.7 Experimental setup

3.7.1 Pot filling with Soil and Biochar

Polyvinyl (PVC) containers of 17 cm diameter and a height of 17 cm were used as pots in the study. A total of 66 pots were used in the study. The pots were filled with soil to a predetermined height to attain the field bulk density value of 1.34 g/cm^3 .Since the field bulk density and volume of pots were known, the weight of soil needed to fill the pot to get the required bulk density was calculated using the equation below.

$$V = \pi r^2 h \; ;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[\,3.14\,]$$

$$M\ (g) = BD\ (g/cm^3) \times V\ (cm^3) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[3.15\,]$$

Where V is volume of cylindrical PVC pot, r, is radius of PVC pot, h, is height of pot, M, is the mass of soil sample and BD is soil field bulk density of soil .

The mass of the soil from the calculation in equation [3.14] was 3.5 kg. This amount of soil was put into the pots leaving height of 5.5 cm in the pots to maintain a constant head of water simulating flooded conditions as in lowland conditions for rice cultivation. Half of the number of the potted soils were amended with biochar at a rate of 50 t/ha of biochar (i.e 30 t/ha of C in biochar). These treatments were replicated three times. All the soils were and then filled with water to field capacity and incubated for 2 weeks and randomized in the screen house. There were thus two levels of biochar application viz., 0 and 50 t/ha.

The rice variety (Jasmine 85) planting stock was obtained from Savanna Agricultural Research Institute (SARI), Nyanpkala in the Northern Region. The seeds were air – dried for three (3) days, sieved and cleaned of debris. Germination test was conducted before planting which. The seeds were nursed in a nursery and transplanted 12 days after seeding and later thinned to 3 seedlings per pot.

Fertilizer were applied to pots one week after transplanting. Two sources of N i.e. cow dung and ammonium sulphate were applied at three rates of zero (0), 50 kg N/ha and 100 kg N/ha to the soils.

The quantity of cowdung (Q) applied per pot for the organic N sources was determined from the formula

$$Q = \frac{R x A}{C}$$

Where R = Rate of application of N

A = area of soil in pot (m^2)

C = nitrogen concentration of cowdung or ammonium sulphate

R= 100 kg N per ha,

Area (A) for pot of diameter 17 cm = 0.0227 m^2

C = 1.2%

Therefore, for cowdung N applied 100 kg per ha,

Q = 0.0189 kg

= 18.91g/pot

Therefore for cowdung N at 50 kg per ha, using the formula above will be 9.45 g.

A similar calculation was made for treatments requiring inorganic N fertilizer i.e. ammonium sulphate.

Basal P and K fertilizers were applied to all the experimental treatments a rates of 40 kg K/ha and 45 kg P_2O_5/ha, respectively from muriate of potash and TSP. There was thus a two biochar rate, two N sources, three N rates and three replicates i.e. 2x2x3x 3 factorial experiment arranged in a completely randomized design giving 36 treatment units. Another set of 36 was added raising the number of experimental units 72 out of which 36 were harvested 48 days after transplanting and the remaining 36 harvested after 94 days.

T1: B_0ON_0 0 t/ha rice husk biochar + 0 kg Organic N

T2: B_0IN_0 0 t/ha rice husk biochar + 0 kg Inorganic N

T3: B_0ON_{50} 0 t/ha rice husk biochar + 50 kg Organic N

T4: B_0ON_{100}	0 t/ha rice husk biochar + 100 kg Organic N
T5: B_0IN_{50}	0 t/ha rice husk biochar + 50 kg Inorganic N
T6: B_0IN_{100}	0 t/ha rice husk biochar + 100 kg Inorganic N
T7: B_1ON_0	**50 t/ha rice husk biochar + 0 kg Organic N**
T8: B_1IN_0	**50 t/ha rice husk biochar + 0 kg Inorganic N**
T9: B_1ON_{50}	50 t/ha rice husk biochar + 50 kg Organic N
T10: B_1ON_{100}	50 t/ha rice husk biochar + 100 kg Organic N
T11: B_1IN_{50}	50 t/ha rice husk biochar + 50 kg Inorganic N
T12: B_1IN_{100}	50 t/ha rice husk biochar + 100 kg Inorganic N

The boldly typed treatments were practically the same so two out of the four were used for the analysis thereby reducing the number of treatments to 10.

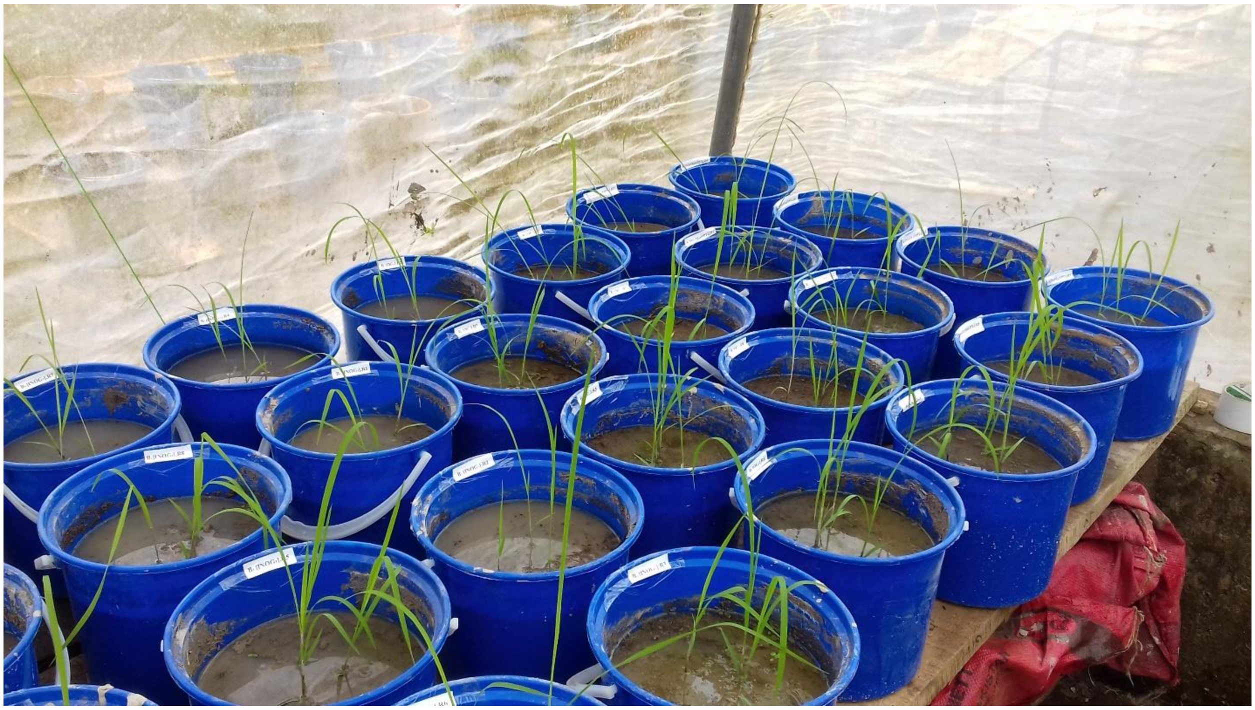

Plate 6 Picture of transplanted rice in pots

Plate 7 Picture of potted rice plants at seven weeks of growth

Table 3. 1 Fertilizer application rates

Fertilizer	Nutrient supplied	Rate (kg/ha)	Amount per pot (g)
Sulphate of ammonia	Nitrogen	100	1.08
Cowdung	Nitrogen	100	18.91
Triple super phosphate	Phosphorus	45	0.23
Muriate of potash	Potassium	40	0.15

A parallel experiment with the same treatments was set up in which case the experiment was terminated at seven weeks. After transplanting a 5.5 cm head of water was maintained to simulate flooded conditions

3.7.2 Experimental Data collection

Plant growth was monitored after transplanting and data on growth parameters taken. After harvesting the dry matter weight was recorded followed by chemical analysis on the biomass to determine some nutrient contents of the straw.

3.7.2.1 Growth Data

Plant height and tiller numbers were recorded weekly for 7 weeks as growth data. Plant height was measured with a meter ruler from the soil surface to the arch of the uppermost leaf. The tiller numbers were recorded by counting the total number of tillers week after week.

3.7.2.2 Plant Biomass yield

Biomass was measured by harvesting the above ground biomass of rice plant from each pot at the end of the 48th and the 94th days of transplanting the rice. On the 48th day after sampling, the dry weight of the straw was noted after oven drying under temperature of 65 ºC for 3 to 5 days. On the

94th day after sampling the rice plants, grains were separated from the straw and the grains were air dried. The straw was oven dried for 3 to 5 days at 65 ºC to a constant weight. On the 94th day after sampling the rice plants, grains were separated from the straw and the grains were air dried. The straw was oven dried for 3 to 5 days at 65 ºC to a constant weight. The total biomass yield was calculated by summing the dry weight of the straw and grain.

3.7.3 Chemical analyses of plant material

The harvested plant samples were subjected to chemical analysis to determine some chemical properties of the harvested plant samples

3.7.3.1 Total Nitrogen and Carbon

The total carbon and nitrogen contents of the plant samples were determined using a Leco Trumac Carbon Nitrogen Sulphur version 1.3 Analyzer. Two hundred milligramme of the plant sample was weighed into platinum crucibles and each mixed with 500 mg of comcat and placed in the furnace of the analyzer. The C and N concentrations in the samples were read after 6 minutes of combustion in a mixture of helium and oxygen gas.

3.7.3.2 Nitrogen uptake

The N uptake by plant was calculated using the formula below

$$\text{Shoot N uptake (mg/pot)} = \text{shoot dry weight (g/pot)} \times \frac{\text{shoot \% N}}{100} \times 1000 \ldots\ldots\ldots.[3.16]$$

3.7.3.3 Total plant phosphorus

Hundred milligrammes of each of the milled shoot and root samples were weighed into 50 mL conical flask and 5 mL of concentrated sulphuric acid (H_2SO_4) was added. The flask was then swirled to ensure that the acid mixed thoroughly with the milled sample and left to stand overnight.

This allowed for a thorough dissolution of the samples by the acid. The flask and its content were then heated on a sand bath for 1 min and H_2O_2 was added drop wise with intermittent swirling till the solution was clear. Deionized water was added to the solution and left to cool, after which the solution was filtered through a No. 42 Whatman filter paper into a 100 mL volumetric flask and made to the mark with deionized water.

A 5 mL aliquot of the digest was pipetted into 50 mL volumetric flask in duplicates and colour developed according to the method of Murphy and Riley (1962) as outlined in section 3.2.2.7.

The shoot total P was determined from the dry matter yield of plant and the plant P% content as:

$$\text{Shoot P uptake (mg/pot)} = \text{shoot dry weight (g/pot)} \times \frac{\text{shoot \% P}}{100} \times 1000 \qquad \ldots\ldots[3.17]$$

3.7.4 Residual soil analysis

Soils were sampled from the pots after harvesting of rice and analysed to determine some chemical properties.

3.7.4.1 Residual Soil pH

Twenty grams (20 g) of the soil sample were weighed in duplicates into 50 mL beakers, Distilled water of 20 mL was added to the samples and stirred continuously for 30 min. The soil suspension was then left to stand for an hour. The glass electrode pH meter (pH-mV-Temp PL-700PV) was standardized and the pH measured as described in section 3.2.2.1. The pH in 1M KCl was also determined.

3.7.4.2 Total Phosphorus for Residual soil

Total phosphorus for the residual soil was determined by digesting 0.2 g of residual soil with 25 mL of a mixture of concentrated HNO_3 and 60% $HClO_4$ in the ratio of 1:1.5 (HNO_3: 60% $HClO_4$).

Distilled water was added to the digest, filtered and made up to volume in a 100 mL volumetric flask with distilled water. Phosphorus in the digest was determined as described by the Watanabe and Olsen (1965) as outlined in section 3.2.2.7. The P content of the samples in triplicates was then read with the spectrophotometer, and the calculations were done.

Total Nitrogen and Total Carbon

The total carbon and nitrogen content of the residual soils were determined using a Leco Trumac Carbon Nitrogen Sulphur version 1.3 Analyzer. Two hundred milligramme of the fine earth fraction of each soil was weighed into platinum crucibles and each mixed with 500 mg of comcat and placed in the furnace of the analyzer. The C and N concentration in the samples were read after 6 minutes of combustion.

Total Phosphorous

Residual phosphorus in the soil samples after harvesting the rice plant was determined. Ten grams of the air dried soil samples (2 mm sieved) were weighed into 100 mL extraction bottles. Fifty millilitres (50 mL) of Bray 1 solution (0.03 M NH_4F in 0.025 M HCl) was added. The soil suspension was shaken for 3 min on a reciprocating shaker at 180 strokes per min, allowed to settle and the supernatant filtered through a No.42 Whatman filter paper into a 100 mL volumetric flask which was made up to the mark with distilled water. Phosphorus in the filtrate was determined using the Watanabe and Olsen, (1965) molybdate blue-ascorbic acid method as described in section earlier section (3. 2. 2. 7).

Data Analyses

The measured crop parameters, nutrient uptake and the residual soil analyses after harvest were subjected to analysis of variance (ANOVA) using Genstat 12th edition to establish if there were any significant difference in treatment effects at $p < 0.05$. Mean separations were done using LSD (0.05).

CHAPTER FOUR

4 RESULTS

4.1 Characterization of soil used

Some physico- chemical properties of the ploughed layer of the soil used in the study are shown in the Table 4.1 The soil is Lima series and is classified as Eutric Gleysol by the Soil Research Institute 1999 according to the FAO/UNESCO classification system (1990) or Aquic Dystroquept according to (USDA) (Dowuona, 1985). The sand content is 32.75%, silt 38.50% and clay content of 28.75% giving it a textural class of clay loam. The soil has bulk density of the ploughed soil layer is 1.34 Mg/m^3.

The soil is strongly acid in reaction with pH in water being 5.0 and in 1M KCl, the pH of the soil sample was 4.1 i.e. very strongly acid. The soil has an organic carbon content of 13 g/kg which is higher than the levels in most soils from the savannah zone of northern Ghana where the average carbon contents are generally lower than 5 g/kg (Nartey *et al*., 1997). The total nitrogen of 0.8 g/kg and available P of 10.76 mg/kg are consequentially higher than the average of most northern Ghana soils (Table 4.1). The C: N ratio of the soil is 16.25. The total phosphorus of the soil series is 124.5 mg/kg which is also characteristic of northern Ghana soils (Nartey *et al*., 1997).

The exchangeable calcium and magnesium contents of the soil sample are 1.8 cmol/kg and 0.32 cmol/kg respectively. The exchangeable potassium is 0.49 cmol/kg whilst the exchangeable sodium the lowest among the exchangeable bases is 0.22 cmol/kg. The soil has an exchangeable acidity (Al^{3+} and H^+) of 0.62 cmol/kg. The effective cation exchange capacity (ECEC) of the soil is therefore very low with a value of 3.46 cmol/kg with a high base saturation of approximately 83%.

Table 4. 1 Some selected physical and chemical properties of the Lima series

Properties	**Values**
Physical properties	
Bulk density (Mg/m^3)	1.34
Sand content (%)	32.75
Clay content (%)	28.75
Silt content (%)	38.50
Textural class	Clay loam
Chemical properties	
pH 1:1 (H_2O)	5.00
pH 1:1 (1M KCl)	4.10
Organic C (g /kg)	13.00
Total N (g /kg)	0.80
C: N	16.25
Total P (mg/kg)	124.50
Available P (mg/kg)	10.76
Exchangeable Ca (cmol(+)/kg	1.80
Exchangeable Mg (cmol(+)/kg	0.32
Exchangeable K (cmol(+)/kg	0.49
Exchangeable Na (cmol(+)/kg	0.22
Exchangeable Acidity cmol(+)/kg	0.62
ECEC	3.42
Base saturation (%)	82.70

$$Biochar\ yield(By) = \frac{Dry\ weight\ of\ biochar(DB)}{Dry\ matter\ weight\ of\ feedstock(DF)} \times 100\% \text{ ………………………….. [3.14]}$$

$$By = \frac{11.5}{20} \times 100\% = 57.5\%\text{……………………………………………………………[3.15]}$$

4.2 Chemical characterization of rice husk feedstock and its biochar derivative

Some selected chemical properties of the rice husk and its biochar derivative used for the study are presented in the Table 4.2. The pH of the rice husk in water was 6.0 whilst that of its biochar derivative was 8.1. The pH of the rice husk in 1M KCl was 5.2 and that of the rice husk biochar was 8.5. The total carbon content of the rice husk is 400.09 g/kg and after charring increased 1.84 times to 738 g/kg. The total nitrogen content of the rice husk feed stock which was 11.5 g/kg decreased by 57.4% to 4.9 g/kg upon charring. The C:N ratio of rice husk which was 34.8 increased six fold after charring using the Kuntan kiln at temperatures between 537.2 °C and 628.1 °C. Total phosphorus content of the rice husk which was 289 mg/kg increased 20.8 times to 6032 mg/kg when it was converted to biochar. The available phosphorus of the rice husk biochar was 2313 mg/kg.

Table 4. 2 Some Chemical properties of the rice husk and its biochar derivative

Parameter	Rice husk	Rice husk biochar
pH (water)	6.00	8.10
pH (1M KCl)	5.20	8.50
Total N (g kg^{-1})	11.50	4.90
Total C (g kg^{-1})	400.09	738.00
C:N	34.80	150.60
Available P (mg/kg)		2313.00
Total P (mg/kg)	289.00	6032.00

4.3 Characterization of Cow dung

The cow dung which was used as a source of organic nitrogen was characterized to know some of its chemical properties and these are presented in Table 4.3. The total nitrogen and total carbon contents of the cow dung were 231 g/kg and 11.8 g/kg, respectively with a C:N ratio of 19.5.

4.4 Soil amendment influence on rice growth parameters

This aspect of the results examines the effects of rice husk biochar and different sources of nitrogen on rice growth. The rice growth parameters included weekly plant height, tiller numbers recordings and the dry matter yield which was taken at 42 days after transplanting (DAT). The grain weight at maturity was also taken at 94 DAT. The effect of biochar on weekly plant height is presented on Table 4.4.

There was no significant difference in plant height one week after transplanting irrespective of whether the soil was amended with biochar or not as plant height was between 48.5 and 50.7 cm. Two weeks after transplanting the rice plants in the un-amended soils were 62 cm, and significantly 5 cm shorter than those in the biochar amended soils. Three weeks after transplanting the difference in height between the plant from the un-amended soils and the biochar amended ones had increased to 6.4 cm. The differences in height progressively increased to the sixth week where the plants from the un-amended soils attained a height of 95. 5 cm with their biochar amended counterparts being 108.1 cm in height

Applying inorganic and organic forms of N fertilizer at different levels resulted in no significant difference in plant height among the various treatments for the various weeks (Table 4.5). The treatments involving inorganic nitrogen fertilizer however recorded higher plant heights compared to the organic nitrogen sources after week 3 (Table 4.5). No lodging was observed for any of the rice plant at any point in time.

Table 4. 3 Some chemical properties of cow dung used

Parameter	Values
Carbon (g/kg)	231.00
Nitrogen (g/kg)	11.80
C:N	19.50

Table 4. 4 Effect of biochar application on plant height

Biochar rates	Wk. 1	Wk.2	Wk. 3	Wk. 4	Wk. 5	Wk.6
B_0	48.5	62.0	77.6	87.4	91.3	95.5
B_1	50.7	67.0	84.0	95.8.	104.3	108.1
LSD	ns	4.9	6.4	7.7	10.8	11.0

Wk: Week

Table 4. 5 Different sources and levels of N on weekly rice plant height*

N Levels	Wk. 1	Wk. 2	Wk. 3	Wk. 4	Wk. 5	Wk. 6
ON_0	58.0	68.8	85.8	94.2	98.3	92.0
ON_{50}	45.0	60.4	74.1	83.1	88.6	100.0
ON_{100}	53.0	67.7	83.5	91.2	92.8	97.0
IN_{50}	46.2	65.1	84.3	95.6	102.5	105.0
IN_{100}	44.2	61.3	76.3	94.2	106.8	114.8
LSD	ns	ns	ns	ns	ns	ns

ON = Organic N source, IN = inorganic N source, ns=not significant

The interaction between different application rates of biochar with different sources and levels of nitrogen resulted in generally no significant difference in the plant height especially from the second week as evident in Table 4.6.

As was for plant height, amending soil with biochar at the rate of 50 t/ha, there was no significant difference in tiller numbers compared with the un-amended soil (Table 4.7).

Similarly, no significant difference in treatment was observed on weekly basis when different sources and levels of nitrogen were applied on the rice plant. The different levels and sources of nitrogen did not result in significant difference in the weekly tiller number count. However, it was only in the treatment where inorganic N fertilizer was applied at 100 kg/ha that tiller numbers increased progressively with time up to the sixth week after transplanting (Table 4.8)

The interaction of biochar with different sources and levels of N did not also result in any significant difference in tiller number as shown in Table 4.9.

4.5 Dry matter and grain yields of rice plant as influenced by soil amendment and application of different nitrogen sources and levels

There was significant difference in dry matter yield between treatments of biochar amended and that of the un-amended soils. The dry matter yield of rice was 12.4 g/pot for treatments where the soil was un-amended with biochar and this was significantly different by 29% to 16.06 g/pot when the soil was amended with biochar at 50 tons/ha ($p = 0.007$) (Table 4.10).

Similarly, grain yield which was 15.9 g/pot in the un-amended soil increased almost 21% to 19.0 g /pot when the soil was amended with biochar soil (Table 4.10).

When no nitrogen was applied, the dry matter yield of rice was 11.86 g/pot which was not significantly different from when organic N was applied at 50 kg N/ha was applied (Table 4.11).

Table 4. 6 Effect of biochar-nitrogen interactions on weekly plant height.

Treatments	Wk.1	Wk.2	Wk.3	Wk.4	Wk.5	Wk.6
B_0ON_0	64.3	70.0	81.7	88.7	91.7	94.7
B_0ON_{50}	42.8	60.2	72.5	80.2	81.8	85.7
B_0ON_{100}	49.3	63.0	81.3	91.7	92.7	97.3
B_0IN_{50}	43.2	60.2	77.3	87.3	92.0	94.3
B_0IN_{100}	42.83	59.0	75.3	89.3	98.3	105
B_1ON_0	51.7	67.7	90.0	99.7	105.0	106
B_1ON_{50}	48.2	62.8	75.7	86.0	105.0	98.3
B_1ON_{100}	57.5	72.3	85.7	90.7	93.0	96.7
B_1IN_{50}	49.33	70.0	91.3	103.8	113.0	115.7
B_1IN_{100}	45.67	63.7	77.3	99.0	115.3	124.0
LSD	7.60	10.82	14.03	18.16	23.06	23.42

Table 4. 7 Influence of biochar on tiller numbers

Biochar rates	Wk.1	Wk.2	Wk.3	Wk.4	Wk.5	Wk. 6
B_0	3.4	7.7	9.4	9.9	10.8	11.0
B_1	3.3	7.4	9.2	9.7	11.4	11.8
LSD	ns	ns	ns	ns	ns	ns

Table 4. 8 Effects of different sources and levels of N on tiller number

N Levels	Wk.1	Wk. 2	Wk.3	Wk. 4	Wk.5	Wk. 6
ON_0	4.3	7.8	9.5	9.5	10.8	10.8
ON_{50}	3.1	8.0	10.0	10.1	11.5	11.5
ON_{100}	3.6	8.6	10.0	10.0	10.6	10.8
IN_{50}	3.0	7.3	9.5	9.8	11.0	11.0
IN_{100}	3.3	6.0	7.8	9.6	11.8	13.1
LSD	ns	ns	ns	ns	ns	ns

Table 4. 9 Influence of biochar nitrogen interactions on tiller number

Treatments	Wk.1	Wk.2	Wk.3	Wk.4	Wk.5	Wk.6
B_0ON_0	4.3	8.0	9.0	9.0	11.0	11.0
B_0ON_{50}	3.3	7.7	10.7	11.0	11.0	11.0
B_0ON_{100}	4.0	8.3	10.3	10.3	10.3	10.3
B_0IN_{50}	3.0	7.3	8.7	9.0	10.7	10.7
B_0IN_{100}	3.6	7.3	8.7	10.3	11.3	12.3
B_1ON_0	4.3	7.7	10.0	10.0	10.7	10.7
B_1ON_{50}	3.0	8.3	9.3	9.3	12.0	12.0
B_1ON_{100}	3.3	9.0	9.7	9.7	11.0	11.3
B_1IN_{50}	3.0	7.3	10.3	10.7	11.3	11.3
B_1IN_{100}	3.0	4.7	7.0	9.0	12.3	14.0
LSD	ns	ns	ns	ns	ns	ns

Table 4. 10 Effects of amending soil with biochar and the influence on dry matter and grain yields

Biochar rate	Dry matter weight (g/ pot) 42 DAT	Grain weight at maturity (g/pot) 94 DAT
B_0	12.4	15.9
B_1	16.0	19.2
LSD	0.9	1.9

Table 4. 11 Nitrogen sources and levels on dry matter and grain yields of rice plant

N Levels	Dry matter weight (g / pot) 42 DAT	Grain weight at maturity (g/pot) 94 DAT
ON_0	11.86	13.23
ON_{50}	11.45	14.21
ON_{100}	13.67	18.34
IN_{50}	15.77	19.22
IN_{100}	18.41	23.07
LSD	1.43	3.11

However, at 100 kg N/ha from cow dung, dry matter increased to 13.67 g/pot. Both inorganic application rates increased dry matter yield significantly to 15.77 and 18.4 g/pot, respectively for 50 kg N/ha and 100 kg N/ha application rates. Dry matter yield was therefore in the order of $0N_0 = ON_{50} < 0N_{100} < IN_{50} < IN_{100}$ .Grain yield trend was similar to that of the dry matter with the inorganic N sources giving higher yields than their organic counterparts.

When both biochar and N at 50 kg/ha from cow dung were amended to the soil, dry matter was 12.47 g/pot which was significantly higher than when the soil was not amended with anything and when the soil was amended with only cow dung N at 50 kg/ha (Table 4.12). On increasing the cow dung N to 100 kg/ha in the biochar amended plot, dry matter increased significantly by 26% to 15.74 g/pot.

Amending soil with 50 t/ha biochar and inorganic N at 50 kg/ha increased dry matter significantly to 17.97 g/pot from that of the un-amended soil (10.42 g/pot) and from when only either of the two amendments was applied. The 17.97 g/pot dry matter yield was also significantly higher than yields obtained from the pots from which biochar and cow dung N at the two rates were applied.

Amending the soil with biochar and fertilizing with sulphate of ammonia at 100 kg /ha increased dry matter yield from that of the biochar amendment and inorganic N at 100 kg/ha by 20% to 20.06 g/pot. In general the interactive effect of biochar at 50 t/ha and N was in the order of $B_1IN_{100} > B_1IN_{50} > B_1ON_{100} > B_1ON_{50}$.

The interactive effects of biochar and N from cow dung at the two rates on grain yield (i.e. comparing treatments B_1ON_{100} and B_1ON_{50}) did not show any significant difference between the two rates of N as grain yield was statistically similar with values between 15.6 and 18.4 g/pot. When biochar was however amended with sulphate of ammonia at 50 kg/ha grain yield was 21.4

g/pot significantly higher than biochar treatments with the cow dung. On adding 50 kg more sulphate of ammonia, yield increased almost 19% to 25.43 g/pot (Table 4.12).

Table 4. 12 The influence of biochar x nitrogen interactions on dry matter and grain yields of rice plant.

Treatments	Dry matter weight at (g /pot) 42 DAT	Grain weight at maturity (g/pot) 94 DAT
B_0ON_0	10.42	11.07
B_0ON_{50}	10.63	12.82.
B_0ON_{100}	11.60	18.25
B_0IN_{50}	13.58	17.03
B_0IN_{100}	15.76	20.70
B_1ON_0	13.08	15.40
B_1ON_{50}	12.47	18.44
B_1ON_{100}	15.74	15.60
B_1IN_{50}	17.97	21.40
B_1IN_{100}	21.06	25.43
LSD	2.02	4.41

4.6 Effects of biochar on N and P uptake

The effect of biochar on uptake of N and P in the plant dry matter is presented in Table 4.13. Uptake of N in rice plants from the un-amended soils averaged 170 mg/pot and this increased 1.3 times to 223 mg/pot when the soil was amended with 50 t/ha biochar.

Amending the soil with biochar significantly improved on the P uptake by the rice plants almost 1.5 times from 79 mg/pot in the un-amended soil to 116.5 mg/pot when the soil was amended with biochar (Table 4.13).

4.7 Nitrogen levels and sources on nitrogen uptake

When no N was applied to the soil, N uptake was 140 mg/pot which was statistically similar to that when cow dung was applied at 50 kg/ha (157 mg/pot) (Table 4.14). When N from the cow dung was increased to 100 kg/ha, N uptake increased significantly from 157 mg/pot to 201 mg/pot which was statistically similar to the 214 mg/pot uptake from sulphate of ammonia N applied at 50 kg/ha. On increasing Ammonium sulphate N to 100kg N/ha the highest uptake of N at 281 mg/pot was attained.

There was significant difference in P uptake when different sources and levels of N were applied. P uptake was lowest when no N source was applied to the rice plant. On amending the soil with cow dung at 50 kg N/ha, P uptake was 81 mg/pot statistically similar to the 77.2 mg/pot observed in the unfertilized soil. Addition of cow dung at 100 kg N/ha increased P uptake significantly to 95.6 mg/pot and further to 107.4 mg/pot when inorganic N at 50 kg/ha was applied. Phosphorus uptake was highest (127.6 mg/pot) when inorganic nitrogen was applied at 100 kg/ha.

4.8 Interactive effect of biochar and nitrogen on N and P uptake

Amending soil with biochar and external input of nitrogen fertilizer increased N uptake (Table 4.15). When the soil was amended with biochar at 50 t/ha and cow dung at 50 kgN/ha. N uptake

Table 4. 13 Effects of biochar on nutrients uptake

Biochar rates	**N uptake (mg/pot)**	**P uptake (mg/pot)**
B_0	170.0	79.0
B_1	223.0	116.50
LSD	26.6	5.86

Table 4. 14 Effects of different sources and levels of nitrogen on plant nutrient uptake

N Levels	**N uptake (mg/pot)**	**P uptake (mg/pot)**
ON_0	140.0	77.2
ON_{50}	157.0	81.0
ON_{100}	201.0	95.6
IN_{50}	214.0	107.4
IN_{100}	281.7	127.6
LSD	42.0	9.2

Table 4. 15 Effects of biochar x nitrogen interactions on plant nutrient uptake

Treatments	N uptake (mg/pot)	P uptake (mg/pot)
B_0ON_0	122.0	65.7
B_0ON_{50}	160.0	69.1
B_0ON_{100}	169.0	74.6
B_0IN_{50}	180.0	83.5
B_0IN_{100}	247.3	102.2
B_1ON_0	154.0	92.8
B_1ON_{50}	158.0	88.8
B_1ON_{100}	230.0	116.6
B_1IN_{50}	187.0	131.2
B_1IN_{100}	316.0	153.1
LSD	59.0	13.1

(158 mg/pot) statistically similar to when the soil was not amended with neither fertilizer nor biochar.

When the N from cow dung was increased to 100 kg/ha N uptake increased almost by 46% to 230 mg/pot. Addition of sulphate of ammonia-N at 50 kg/ha gave similar uptake (187 mg/pot) as when cow dung at 100 kg/ha was applied to the biochar amended soil albeit significantly higher N uptake than the cow dung-N at 50 kg/ha. The interactive effect of biochar and sulphate of ammonia N at 100 kg/ha on rice plant N uptake was significantly the highest with a 29% increase over the same biochar amended soil with sulphate of ammonia-N at 50 kg /ha to 316 mg/pot

Amending soil with biochar and cow dung at 50 kg N/ha increased P uptake significantly over that in the un-amended soil (Table 4.15). Plant P uptake from the B_1ON_{50} which was 88.8 mg/pot increased to 116.6 mg/pot when the nitrogen content in the cow dung was increased to 100 kg/ha (B_1ON_{100}). On amending the soil with both biochar and sulphate of ammonia N at 50 kg /ha, P uptake by rice plants was 131.2 mg/pot i.e 15 mg/pot more than plants from B_1ON_{100}. Further increase of urea-N to 100 kg/ha on the biochar amended soil increased P uptake by the rice plants to 153.1 g/pot (Table 4.15)

4.9 Effects of Amendments on residual soil chemical properties

Where soil was amended with biochar at 50 t/ha, the soil residual total nitrogen, total P, total C were significantly higher than where the soil was un- amended with biochar i.e. no biochar was added (Table 4.16). Residual pH which was on the average 4.9 in the un-amended soils increased by 0.5 pH units to 5.4. Biochar amendment increased residual carbon content by 45% from 11.2 to 20.4 g/kg. Total N content almost doubled from 0.32 g/kg to 0.63 g/kg with total P increasing by 64% from 168 g/kg to 275 g/kg.

Table 4. 16 Influence of biochar on soil properties (residual soil).

Treatments	pH	Total C (g/kg)	Total N(g/kg)	Total P(mg/kg)
B_0	4.9	11.2	0.32	168.0
B_1	5.4	20.4	0.63	275.0
LSD		7.0	0.15	49.3

4.9 Influence of nitrogen sources and levels on residual soil chemical properties

There were generally no significant difference in pH of the residual soil of the various treatments that received N fertilization from the two sources as residual pH was between 5.0 and 5.3. The unfertilized soil had residual C content of 14.1 g/kg similar to the 13 g/kg before cultivation. On fertilization with cow dung equivalent of 50 kg N/ ha, however, residual C increased significantly to 15.9 g/kg (Table 4.17). Doubling the N from cow dung to 100 kg/ha increased residual C by 17% from that of the un-amended soil to 18.0 g/kg. Inorganic N application from sulphate of ammonia at the two rates gave similar residual carbon levels (15.4 g/kg) as that of ON_{50}.

Total N of the soil before cultivation which was 0.8 g/kg (Table 4.1) decreased to 0.33 g/kg after rice cultivation in the unfertilized treatments (Table 4.17). This residual N in the unfertilized soil was not significantly different from N concentrations in soils (0.32 - 0.35 g/kg) that received inorganic N fertilizations. Residual N in the organically N amended soils (0.62 to 0.76 g/kg) were similar to the levels before cultivation but about twice more than their inorganically N fertilized soils.

It is worthy of note that apart from the treatments which were fertilized with cow dung at N equivalent of 100 kg/ha and which had residual total P of 323 mg/kg, all the other treatments had statistically similar P contents ranging between 173 mg/kg and 195 mg/kg.

4.10 Effect of biochar and N interaction on Residual soil chemical properties

Treatments with biochar but with or without N fertilization had residual pH in water after harvest being similar to the 5.0 before cultivation (Table 4.18). On amendment with biochar at 50 t/ha and inorganically N fertilizing with sulphate of ammonia at both 50 and 100 kg N/ha, residual pH did not vary significantly from that of the soil before cultivation as there was just a marginal increase of between 0.1 unit. However, on amending the soil with biochar and fertilizing with cow dung at the two N rates residual pH was 5.5 in B_1ON_{50} soils and 5.9 for B_1ON_{100} soils. These respective increases of 0.5 and 0.9 pH units above that of the soil before cultivation are significant (Nartey *et al*., 2000).

Residual organic carbon in soils with no biochar but fertilized with either organic or inorganic sources of N were significantly not different from each other with levels of the nutrient between 11.3 and 12.4 g/kg. The organic carbon levels in these soils were however significantly higher than the levels in the un-amended soils (9.4 g/kg) (Table 4.18). Amendment of biochar and N fertilization of the soils increased residual OC contents more than two times with the B_1ON_{100} soil having significantly the highest concentration of 23.5 g/kg. The B_1ON_{50}, B_1IN_{50} and B_1IN_{100} had statistically similar OC concentrations of between 19.6 and 20.3 g/kg.

It is note-worthy that though biochar- N application interaction was significantly higher in residual N than the soil before amendments, it was only the B_1ON_{100} treatment significantly had higher residual values than in instances where only one of the amendments was applied. There was twice as much residual N in the organically amended plots than their inorganically amended plots at the same rate after harvest.

There were no significant differences between the other biochar-nitrogen treatments and treatments that had received either biochar alone or N fertilization alone (Table 4.18). In fact, residual N in the B_1ON_{100} was more than seven times in the soil with no amendment (B_0ON_0) and 2.1 times more than in $B_0IN_{100,}$ and 1.25 times more than before cultivation.

There was no clear trend in the residual total P. However, the B_1ON_{100} treatment seem to have accumulated the highest concentration of 367 mg/kg P almost thrice that in the soil before cultivation.

Table 4. 17 Influence of N on residual soil chemical properties

N Levels	**pH**	**Total C (g/kg)**	**Total N (g/kg)**	**Total P(mg/kg)**
ON_0	5.1	14.1	0.33	193
ON_{50}	5.0	15.9	0.62	173
ON_{100}	5.3	18.0	0.76	323
IN_{50}	5.1	15.4	0.32	173
IN_{100}	5.1	15.4	0.35	195
LSD		1.22	0.24	Ns

Table 4. 18 Influence of biochar nitrogen interactions on residual soil chemical properties

Treatments	pH	Total C (g/kg)	Total N (g/kg)	Total P(mg/kg)
B_0ON_0	4.9	9.4	0.14	127
B_0ON_{50}	4.6	11.7	0.31	150
B_0ON_{100}	4.8	12.4	0.52	280
B_0IN_{50}	5.1	11.2	0.30	163
B_0IN_{100}	5.1	11.3	0.22	120
B_1ON_0	5.3	18.8	0.53	260
B_1ON_{50}	5.5	20.3	0.78	297
B_1ON_{100}	5.9	23.5	1.00	367
B_1IN_{50}	5.1	19.6	0.35	183
B_1IN_{100}	5	19.6	0.48	270
LSD		1.7	0.35	Ns

CHAPTER FIVE

5 DISCUSSION

5.1 Characteristics of native soil

The soil being clay loam would hold an appreciable amount of water and that may account for its suitability for rice production by the natives. The soil has medium bulk density of 1.34 Mg/m^3 due to relatively high amount of silt and clay fractions.

The acidic nature (pH of 5.0 in water) could be as a result of the annual ponding of the soil for rice production with concomitant leaching of bases culminating in decrease in pH. This corroborated by the low exchangeable base concentration of 2.83 cmol/kg. This pH is below the average value of 6.5 (Foth and Ellis, 1997) as being ideal for good availability of plant nutrients in mineral soils. The continuous application of sulphate of ammonia as the main N source for rice cultivation in the area could have also contributed to the acidic nature of the soil. Even though the pH of the soil is acidic, inland valley soils are impounded by the rain water most of the time thus creating the lowland condition and this can lead to a shift up of the pH of the flooded soil.

The organic carbon content of the soil (13 g/kg) which is unusually higher than the average of northern Ghana soils (Nartey *et al*., 1997; SRI, 2009) could be as a result of the continuous use of cow dung for rice farming in the area and also the relatively higher moisture content of the soils due to low land rice production that slows down decomposition of organic matter.

Despite the total P of the soil being 124 mg/kg, the available phosphorus of the soil is 10.76 mg/kg which is high for soils in Northern Region of Ghana. The use of cow dung by farmers when planting rice might have contributed to the relatively higher Bray available P and total N recorded. Otherwise, these soils in the Northern Region are highly weathered and contain iron and aluminium oxides and oxyhydroxides (sesquioxides) which have the capacity to sorb very large added P or native P thereby transforming them into Fe- and Al-bound forms (Nartey *et al*., 1997)). The low CEC and hence basic cations of the soil, could be attributed to factors such as the low organic matter and kaolinitic nature of clay as found in similar soils elsewhere in northern Ghana (Nartey *et al*., 1997). The generally low fertility status of the soil would require for an external input fertilizer to increase the productivity of the soil.

5.2 Characteristics of rice husk and rice husk biochar.

The higher biochar pH (8.1) than its feedstock (6.0) is attributed to the chemical cracking of hemicellulose and cellulose during pyrolysis which lead to the release of organic acids and phenolic substances (Struebel *et al*. (2011); Shinogi and Kanri (2003). These acids react with basic cations in the feedstocks to form alkaline salts which increase the pH of biochar. According to Yuan *et al* (2011), the increase in pH is due to the formation of ash that contains Ca, Mg, K and Na during the pyrolysis process.

During pyrolysis the aliphatic carbon groups in feedstock are condensed into more recalcitrant aromatic carbon leading to a higher concentration per unit weight (Sohi, 2009) and this may account for the 1.84 times more carbon in the biochar than its feedstock from which it was derived. Carbon content of the biochar product increases with increasing temperature (Joseph, 2009). Biochar charring temperatures above 500 °C commonly produce materials with C contents greater than 80 percent. At temperatures between 400 and 500 °C biochars have C contents that range from 60 to 80 percent and biochars produced at low temperatures (< 350 °C) have C content that varies from 15 to 60 percent (Joseph, 2009). In this study, the charring was done at the temperatures of between 537.2 ℃ and 628.1 ℃. It is therefore not surprising that the concentration of carbon was 73.8% with a biochar yield of 57.5% when the ‘Kuntan’ kiln was used for the charring.

The total nitrogen content of the rice husk is 11.5 g/kg this is almost double the biochar total nitrogen value of 4.9 g/kg. The 57.4% decrease in nitrogen content of rice husk biochar after charring the feed stock is due to the volatilization of nitrogen during charring process and this is corroborated by Shinogi and Kanri (2003) who found out that about half of N is lost during pyrolysis as temperature increases from 350 to 600 °C. Significant N losses (60-80 percent) have also been reported for biochars produced from rice husks (Bagreev *et al*., 2001).

The higher C:N ratio of biochar than the feedstock is as a result of the carbonization process explained earlier which led to higher biochar carbon content and an attendant decrease in total N relative to the feedstock. Thus, the six-fold increase in C:N ratio of biochar over that of the feedstock is a matter of consequence This high value of C:N ratio of biochar shows that biochar will not easily decompose in the soil and thus would sequester more carbon into the soil to greatly improve carbon stocks of northern Ghana soils should the material be used.

Contrary to N, the total P content of the biochar is higher than the P content of the feedstock. Volatilization of P occur at higher temperatures between 700 °C and 800 °C (DeLuca *et al*., 2009). Since charring was done at temperature below 700 ℃, it is not likely that P was volatilized in this study. The total P content of the biochar was far higher (6032 mg/kg) than that in the feedstock (289 mg/kg) and this is as a result of conversion of organic P to the inorganic form during pyrolysis. The release of the inorganic orthophosphate ions also combines with the liberated Ca to form Ca-P compounds which are not readily soluble and hence increasing significantly the total P contents of the biochar (Lehman, 2007). This in part, may explain why this biochar type has a small available P of 2313 mg/kg.

5.3 Characteristics of Cow dung

The total carbon content of cow dung was 231g/kg and total nitrogen content of 12 g/kg generating a C:N ratio of 19.5. With relatively low C:N ratio the cow dung will enable the manure to mineralize easily and supply the soil with high nitrogen content than biochar within a growing season.

5.4 Influence of amendments on Growth parameters

Significantly higher weekly plant height was recorded for the biochar amended soils over the non biochar amended ones indicating that just adding biochar at 50 t/ha improved growth of the rice plant as indicated by the increase in plant height. The increased plant height in biochar amended soil over non biochar amended soil is due to the more readily available N in the biochar amended soil as evident in the almost twice more total N in the residual analysis of the biochar amended soil than its un-amended counterpart. The higher available N in the biochar amended soil could have promoted more chlorophyll formation to enhance plant growth as reflected in superior dry matter and grain yield in rice plants from the biochar amended soils. The rice was planted under flooded conditions and therefore the N from the non biochar amended soil could have been leached out faster explaining superior height of rice plants from the biochar amended soils. This is further corroborated by the 1.3 times higher uptake of N by rice plants from the biochar amended soils over the un-amended ones

The non-significance in plant height when different levels of N from both cow dung and sulphate of ammonia on height of rice plant confirms that biochar is responsible for increase in plant height of the rice plants. There was no positive influence of biochar alone and in combination with N from the two sources implying that biochar at 50t/ha could not be used in boosting rice yield through tiller formation.

5.5 Influence of amendments on dry matter matter yield

The dry matter yield per pot was significantly higher in the biochar amended soils than the un-amended biochar soils due to higher availability of N as explained earlier which is also corroborated by the superior uptake of 1.3 times more N and 1.5 times more P by rice plants from the biochar amended soils with respect to the un-amended soils. Thus, with higher uptake of the two major nutrients N and P, which translated into higher vegetative growth, it stands to reason that rice plants from the biochar amended soils had 29% more dry matter yield than their counterparts. The results are in accordance with Milla *et al*. (2013) who also found out that applied biochar improved biomass production by increased plant weight.

The non-significance in straw dry matter of cow dung-N at 50 kg N/ha could be due to lower content of nitrogen in cow dung for plant uptake compared to relatively higher N content of N applied at 100 kg. With regards to the inorganic N sources at the two rates, there were significant increases in dry matter weight over the un-amended soil could be due to the more readily available N in the latter three N rates. The fact that straw dry matter of rice increased with increasing N amendment especially with the Sulphate of ammonia application and the dry matter was higher in even the inorganic source at 50 kg N/ha than the organic source at 100 kg N/ha confirm the higher availability in the inorganic sources than the organic sources. The result is in accordance with that of Chaturvedi (2005) who reported an increase in dry matter accumulation following increased nitrogen application rates.

The organic source would be mineralizing slowly especially under flooded conditions releasing its available N slowly as against the inorganic source which is made up of readily available N. It therefore stands to reason that all the rice plants in the inorganic treatments had higher dry matter contents per pot as N is a major nutrient in chlorophyll formation. This higher availability of N from the inorganic sources than the organic sources is further corroborated by superior N uptake from the inorganic source to the organic sources at the same rate and twice as much residual N in the organically amended plots than their inorganically amended plots at the same rate after harvest.

The positive interactive effect of biochar and nitrogen on dry matter yield of rice which did not exist on plant height and tiller numbers indicates that for rice production on the Lima Series with the two amendments dry matter is enhanced more than height and tiller numbers. For increased yield therefore, farmers should rather increase number of seeds per hill if they are planting at stake or increase plant density when they are transplanting.

The fact that there was no significant increase in dry matter yield over the un-amended soil when 50 kg N from cow dung was applied to the soil but there was when biochar was added to the same treatment goes to show the positive effect of biochar on rice production. Biochar may have helped in faster N mineralization from cow dung (Milla *et al*., 2013)).

The generally higher dry matter (DM) yields when both biochar and N were applied to Lima series over the un-amended soils and the DM of rice being in the order of $B_1IN_{100} > B_1IN_{50} > B_1ON_{50}$ B_1ON_{100} could be attributed to the increased availability of nitrogen for rice uptake due to enhanced nutrient retention brought about by biochar addition. The high surface area of biochar according to Liang et al. (2006), enhances absorption of $NH_4^+$and NO_3^- thereby reducing leaching losses and offers a mechanism for developing slow release fertilizer which in turn improves nutrient use efficiency and increase the crop yield (Sarkhot *et al*., 2012). Nitrogen availability in the order of $IN_{100} > IN_{50} > ON_{100} > ON_{50}$ was enhanced on addition of biochar.

5.6 Influence of amendments on grain yield

Nitorgen and P are known to have a major influence in rice grain yield (Purseglov, 1972). With respective 1.3 and 1.5 times more uptake of N and P in rice from the biochar amended soils than their un-amended counterparts, it stands to reason that grain yields in rice grown in the biochar amended soils are 21% more than their counterparts grown in the un-amended soils. Grain yield generally followed the pattern for DM yield and not plant height or tiller numbers. It thus appears that N uptake was translated into dry matter and grain production rather than tiller numbers and plant height.

Applying inorganic nitrogen fertilizer led to higher grain yield over the organic nitrogen fertilizer because chemical fertilizer offers nutrients that are readily available and soluble in soil solution to plants. With higher availability of N from the inorganic sources, it is expected that there would be lower residual N. This is evident in the significantly lower residual N in the Lima series to which the inorganic forms of N relative to the non N amended ones (Table 4.17). Nutrient availability from organic sources is due to microbial action (mineralization) which normally takes a longer time hence delay in release of nutrients for plant uptake (Miller, 2007). On the contrary the organically amended soils generally had almost twice as much residual N than their inorganic counterparts at the same application rates and non N amended soils. This has implication for continuous use of the soils. With application of sulphate of ammonia, there still seem to be mining of nutrients from the inherent fertility of the original soil as residual N which was 0.8 g/kg in the soil before cultivation had decreased by about between 56% and 60% to between 0.32 and 0.35 in the inorganically N amended soil. The organically amended soils especially the cow dung applied at 100 kgN/ha seem to be maintaining the fertility of the soil as there was marginal decreases of only 5% and 22.5%, for the cow dung at 50 kgN/ha

It is thus clear that the use of inorganic source of nitrogen produced better response to yield than organic source of nitrogen at the expense of maintaining soil fertility. Grain yield increased with increasing rates of nitrogen application. The increase in grain yield in response to application of N fertilizers is probably due to the enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation. These results are supported by the findings of Mandal *et al*. (1992). Furthermore, increased nitrogen application can lead to increase in the protein percentage, which in turn increased the grain weight (Kausar *et al*, 1993).

The highest grain yield of the harvested rice when biochar was combined with inorganic nitrogen applied at 100 kg/ha over the control and when either of the two amendments was applied alone is consistent with the results of Steiner *et al*., (2007) and Widowati *et al*., (2011) who reported an improved crop yield resulting from the application of fertilizer along with biochar due to better N utilization. The reason behind better nutrient utilization was the decrease in N losses due to more NH_4^+ adsorption on biochar surfaces (Chan *et al*., 2008; Masulili *et al*., 2010). The result is also similar the results of Masulili *et al*. (2010) who in a pot experiment found that the combined effect of urea and biochar produced more grain yield than the control. Grain yield increase was higher at where biochar was combined with inorganic nitrogen than with the same quantity of organic nitrogen.

5.7 Influence of amendment on nutrient uptake.

The amendment of soil with biochar and nitrogen sources resulted in an increased uptake of some soil nutrients. High N uptake of rice at harvest stage was recorded among treatments amended with biochar. The results demonstrated that biochar not only promoted fertilizer N utilization but also enhanced soil N availability to the plant. Biochar can act as a soil conditioner, altering the soil chemical and microbial properties and resulting in an increased uptake of soil nutrients that were not available in otherwise poor soils (Shen *et al*., 2016; Van Zwieten *et al*., 2010).

The higher uptake of N and P by rice when biochar alone was applied to the soil shows the positive effect of the amendment in making nutrient available. The biochar may have interacted with the native N resulting in faster mineralization with a concomitant release of more available N (Yeboah *et al*., 2009). The biochar itself contains available P (2313 mg/pot) which may have been made available to the crops and hence the higher uptake in the biochar amended plots

Application of inorganic nitrogen resulted in a significantly higher nitrogen uptake by rice than when organic N was applied due to the fact that the inorganic nitrogen source contains more readily available nitrogen compared to the organic nitrogen.

The interaction of biochar with nitrogen resulted in a higher nitrogen and P uptake especially when biochar was applied with inorganic nitrogen at 100 kg/ha due to enhanced availability of the two nutrients. Similar results were reported by DeLuca *et al*. (2009) who stated that biochar added to soil with a nitrogen source yielded an increase in net nitrification and improved the nitrogen availability to the plants. The outcome is also similar to the results of Yeboah *et al*. (2009) who noted that biochar increased the uptake of nitrogen in plants. The reason for better N content, uptake and N recovery might be the higher nutrient retention capacity of biochar amended soil. The higher intake of both N and P anywhere the two nutrients were applied together could also be due to the synergistic relationship between the two nutrients (Marschner, 1986). Higher availability and uptake of one would lead to higher uptake of the other and vice versa.

Phosphorus uptake significantly increased with the application of biochar. Amending soil with biochar resulted in an increased P content of 37 mg/pot over the un-amended soils. The increase in P uptake following amendment with biochar is due to the higher P content of biochar which might have contributed to increase in soil P after amendment and this is supported by by Milla *et al*., (2013) who reported that addition of nutrient enriched biochar increased the available phosphorus. Similar results were also recorded by Lehmann (2007) who also reported that addition of biochar significantly increased plant growth and nutrition and corroborated by Angst and Sohi (2013) and Yao *et al.*, (2013) who found that biochar adsorbed P more efficiently and became bio-available over a period of time which stimulated plant growth.

5.8 Effects of amendments on residual chemical properties of soil

Rice husk biochar has been found to increase pH of Ankasa and Tikobo series, two of the strongly acid soils in Ghana by 1 pH unit after six weeks of incubation (Frimpong Manso, 2017) and the increment has been ascribed to high levels of total and exchangeable Ca and especially Mg in biochar. The 0.5 increase in pH of the biochar amended soils with respective to the un-amended soil after harvest) is significant as a result of the release of basic cations especially the alkali earth metals Ca and Mg found in rice husk biochar (Nartey *et al*. 2000 ; Frimpong Manso, 2017). The increase in soil pH could also be attributed to the influence of higher pH of 8.1 of rice husk biochar on the soil. Furthermore, Lu *et al*. (2014) also observed the liming effect in a subtropical paddy soil, which was accentuated by the higher dose of biochar with smaller particle size. There was generally no change in pH of the soils when N from the two sources at the two rates were applied to the soil. Being under flooded condition, nitrification of NH_4^+ from the two sources were suppressed and hence no change in pH. The interactive effect of biochar and N led to respective 0.6 and 1.0 pH unit increase in the cow dung applied at 50 and 100 kg N /ha mainly due to biochar offering sites for increased mineralization of organic N to NH_4^+ with a concomitant release of OH^-

to raise the pH. It therefore stands to reason that residual pH increase was higher in the B_1ON_{100} soil than the B_1ON_{50} counterpart soils because of the higher organic N content of the former.

The rice husk biochar has a high C: N ratio of 150.6, it is expected that the carbon will be more stable in the biochar amended soil leading to higher soil carbon levels after cultivation accounting for the higher C contents of 20.4 g/kg compared to the 11.2 of the un-amended soil. Besides, aging of biochar has also been found to increase the carbon content (Sohi *et al*.,2009). The rice husk biochar amended to the soil at 50 tons/ha contained 4.9 g/kg total N and 6032.0 mg/kg total P and these contents may have contributed to the doubling of residual TN contents and the 64% increase in total P over the contents in the un-amended soil. The carbon contents of the organic nitrogen amended soils recorded higher soil total carbon compared to the inorganic sources of nitrogen with application of organic nitrogen at 100 kg/ha recording the highest residual soil carbon of 1800 mg/kg. This is mainly due the relatively higher carbon content of organic source of nitrogen compared to the inorganic forms. The highest residual organic carbon accumulations in the soil (23.5 g/kg) was found when cow dung at 100 kgN/ha was combined with biochar at 50 tons/ha and this could be due to the contribution of both recalcitrant carbon from biochar and a more labile organic carbon from the cow dung.

It is therefore clear that addition of both biochar and cow dung tends to sequester more carbon in Lima soils. There must however be continuous monitoring of the different carbon pools in these soils to ascertain which fraction would enhance soil productivity and how long the carbon content would persist with continuous cultivation.

The highest residual N and P in the cow dung amended soil at 100 kg N per ha could be due to the levels in the cow dung and the relatively slow mineralization because of the anaerobic conditions under which the rice was cultivated. This holds promise for subsequent cultivation of the crop since the residual N concentration (0.76 g/kg) in the soil is similar to the level before cultivation (0.8) g/kg whilst there has been an increase in total P levels from 124.5 mg/kg to 323 mg/kg.

The interaction of biochar with nitrogen from cow dung applied at 100 kg N/ha resulted in the only significant difference in residual soil total nitrogen among the treatments due to the two amendments possibly increasing CEC of the soil to hold more NH_4^+ and thereby decreasing leaching. Under flooded conditions, nitrification would be minimized and thus the prevalent form of N in the soil would be NH_4^+. With an increase in CEC by the two amendments viz. biochar and cow dung, it stands to reason more ammonium would be retained. With a higher organic N which would not decompose readily, it is a matter of consequence that residual total N and P would be highest in the B_1ON_{100} soil. The highest residual total P in the B_1ON_{100} soil is as a result of the contribution of P from the 50 ton/ha biochar and the cow dung total P applied.

5.9 Nitrogen Use Efficiency (NUE)

To assess the effectiveness of the biochar on nitrogen retention, the nitrogen use Efficiency (NUE) was estimated.

The Nitrogen Use Efficiency (NUE) was calculated according to the formula by (Baligar, *et al.*, 2007).

$$\text{NUE} = \frac{Nutrient\ uptake\ \text{F}(mg) - Nutrient\ uptake\ C(mg) \times 100}{Quantity\ of\ nutrient\ applied\ (mg)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [5.1]$$

Where F = Uptake in soil at specific N application rate and

C = Uptake in un-amended soil

Table 5. 1 Nitrogen use efficiency of treatments.

Treatments	NUE%
B_0ON_0	-
B_0ON_{50}	28.31
B_0ON_{100}	20.79
B_0IN_{50}	51.32
B_0IN_{100}	55.44
B_1ON_0	-
B_1ON_{50}	31.85
B_1ON_{100}	47.78
B_1IN_{50}	57.52
B_1IN_{100}	85.84

The NUE shows the ability of the plant to obtain N as a nutrient from the soil (Baligar *et al.*,2007). In calculating the NUE, the average equivalent N in both organic and inorganic sources of nitrogen were used as the amount of N applied per pot. This translated to 1080 mg per pot for N_{100} rate and 540 mg N per pot for N_{50}. The NUE of the various fertilized amendments are shown in Table 5.1. The nitrogen use efficiency from the Table 5.1 above shows a higher efficiency in the biochar amended soils than the non biochar amended soils. The highest nitrogen use efficiency (85.84%) was recorded when biochar was amended with Ammonium sulphate N at 100 kg/ha. This represents an increment of 55% over application of ammonium sulphate N at 100 kg/ha without biochar.

CHAPTER SIX

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The results of the research show that rice husk biochar produced from the rice husk feedstock had a higher pH of 8.1 compared to that of the feedstock of 6.0. The charring of rice husk increased the total carbon content of the biochar to almost about two folds that of the rice husk feedstock. Total P content of the charred material was also higher than that of the feedstock.

The results of the experiment also show that there was significant difference in some of the growth parameters of rice when biochar was applied and where no biochar was applied to treatments. Parameters such as plant height, grain weight, straw weight, nutrient uptake, residual soil carbon and nitrogen were influenced by the application of biochar. Rice yield was higher at where soil was amended with biochar as compared to soil un-amended with biochar.

Plant height, tiller number, grain yield and nitrogen uptake were positively influenced by the use of inorganic nitrogen fertilizers compared to the organic fertilizers applied at the same rate from different levels.

The results also showed positive effects of biochar on nutrient uptake. Uptake of N and P were higher in the biochar amended soils than where no biochar was applied.

The biochar amended soils showed increase in total C in the residual soil samples. The residual soil analysis also showed relatively higher total P and total N in the biochar amended soils than soil un-amended with biochar.

Results from the residual soil analysis showed that the use of organic nitrogen sources like cow dung will be beneficial in the Northern Region soils because of the high nitrogen and carbon contents of the residual soil implying that rice grown on the same soil in the subsequent season will benefit from the residual soil nitrogen from the organic nitrogen amended soils.

Finally the nitrogen use efficiency was higher in the biochar amended soils compared to the non-amended ones

6.2 Recommendations

To increase yield of rice in the Northern Region, it is recommended that the nitrogen fertilizer (sulfate of ammonia) be applied together with biochar. The study did not however look at how biochar and nitrogen will influence rice growth in different moisture regimes under lowland conditions especially under the inland valley moisture regime. It is, therefore, recommended that an experiment of this nature be undertaken under field condition to how biochar nitrogen interaction will influence rice growth under different moisture regimes. It is also recommended that another experiment that involve interaction of different rates of organic and inorganic sources of nitrogen with biochar be undertaken in future to observe the growth on yield of rice.

Results from the study showed that addition of rice husk biochar prepared from the “Kutan” kiln combined with organic or inorganic nitrogen will contribute to the increase in yield of rice.

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APPENDICES

Appendix B: ANOVA tables for Biochar Levels, Nitrogen Sources and levels and biochar nitrogen interaction

Variate: Tiller_No_WK_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	0.8333	0.8333	1.09	0.310
N	4	6.6667	1.6667	2.17	0.109
B.N	4	0.6667	0.1667	0.22	0.926
Residual	20	15.3333	0.7667		
Total	29	23.5000			

Variate: Tiller_No_WK_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	0.833	0.833	0.35	0.560
N	4	23.867	5.967	2.52	0.073
B.N	4	11.333	2.833	1.20	0.343
Residual	20	47.333	2.367		
Total	29	83.367			

Variate: Tiller_No_WK_3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	0.300	0.300	0.17	0.682
N	4	19.133	4.783	2.76	0.056
B.N	4	12.867	3.217	1.86	0.158
Residual	20	34.667	1.733		
Total	29	66.967			

Variate: Tiller_No_WK_4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	0.300	0.300	0.12	0.736
N	4	1.667	0.417	0.16	0.955
B.N	4	12.867	3.217	1.25	0.321
Residual	20	51.333	2.567		
Total	29	66.167			

Variate: Tiller_No_WK_5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	2.700	2.700	0.59	0.453
N	4	5.667	1.417	0.31	0.869
B.N	4	1.800	0.450	0.10	0.982
Residual	20	92.000	4.600		
Total	29	102.167			

Variate: Tiller_No_WK_6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	4.800	4.800	0.77	0.389
N	4	23.467	5.867	0.95	0.458
B.N	4	3.200	0.800	0.13	0.970
Residual	20	124.000	6.200		
Total	29	155.467			

Variate: Plant_hiegth_WK1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	29.01	29.01	1.28	0.272
N	4	850.28	212.57	9.36	<.001
B.N	4	423.45	105.86	4.66	0.008
Residual	20	454.00	22.70		
Total	29	1756.74			

Variate: Plant_hiegth_WK2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	208.03	208.03	4.86	0.039
N	4	334.25	83.56	1.95	0.141
B.N	4	143.55	35.89	0.84	0.517
Residual	20	855.83	42.79		
Total	29	1541.67			

Variate: Plant_hiegth_WK_3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	304.01	304.01	4.31	0.051
N	4	661.03	165.26	2.34	0.090
B.N	4	143.37	35.84	0.51	0.730
Residual	20	1409.83	70.49		
Total	29	2518.24			

Variate: Plant_hiegthWK_4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	529.2	529.2	5.11	0.035
N	4	610.5	152.6	1.47	0.247
B.N	4	253.4	63.3	0.61	0.659
Residual	20	2071.3	103.6		
Total	29	3464.5			

Variate: Plant_hiegthWK_5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	1274.0	1274.0	6.24	0.021
N	4	1281.5	320.4	1.57	0.221
B.N	4	361.2	90.3	0.44	0.776
Residual	20	4081.5	204.1		
Total	29	6998.2			

Variate: Plant_hiegth_WK_6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	1190.7	1190.7	5.67	0.027
N	4	1808.0	452.0	2.15	0.112
B.N	4	430.1	107.5	0.51	0.728
Residual	20	4199.3	210.0		
Total	29	7628.2			

Variate: Grain Weight (grams) at maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	80.688	80.688	12.05	0.002
N	4	381.637	95.409	14.24	<.001
B.N	4	21.234	5.308	0.79	0.004
Residual	20	133.967	6.698		
Total	29	617.526			

Variate: Straw weight at six weeks (grams)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	100.723	100.723	71.21	<.001
N	4	201.369	50.342	35.59	<.001
B.N	4	11.249	2.812	1.99	0.003
Residual	20	28.290	1.414		
Total	29	341.631			

Variate: P uptake

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	10543.13	10543.13	177.84	<.001
N	4	10146.19	2536.55	42.79	<.001
B.N	4	1050.07	262.52	4.43	0.02
Residual	20	1185.69	59.28		
Total	29	22925.07			

Variate: N uptake at…………..

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	0.017424	0.017424	14.24	0.001
N	4	0.073257	0.018314	14.97	<.001
B.N	4	0.004480	0.001120	0.92	0.04
Residual	20	0.024470	0.001223		
Total	29	0.119631			

Variate: Analysis of variance for Residual_soil total_C %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	6.36457	6.36457	617.12	<.001
N	4	0.48144	0.12036	11.67	<.001
B.N	4	0.07856	0.01964	1.90	0.049
Residual	20	0.20627	0.01031		
Total	29	7.13084			

Variate: Analysis of variance for Residual_soil_total_P %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	86403.	86403.	20.59	<.001
N	4	85133.	21283.	5.07	0.005
B.N	4	18147.	4537.	1.08	0.392
Residual	20	83933.	4197.		
Total 29 273617.					

Appendix 2a: Analysis of variance for Residual_soil total_N %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B	1	0.0067410	0.0067410	15.73	<.001
N	4	0.0095065	0.0023766	5.55	0.004
B.N	4	0.0017176	0.0004294	1.00	0.0030
Residual	20	0.0085689	0.0004284		
Total	29	0.0265340			