# KWARA STATE UNIVERSITY, MALETE, NIGERIA

## SCHOOL OF POSTGRADUATE STUDIES (SPGS)

# IMPACTS OF BIOCHAR SUPPLEMENTED WITH POULTRY MANURE ON GROWTH OF *AMARANTHUS CAUDATUS (L*), NUTRIENT UPTAKE AND SOIL PROPERTIES

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**19/17MCP/00002**

***MARCH, 2022***

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**A M.Sc. THESIS SUBMITTED**

***BY***

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**DEPARTMENT OF CROP PRODUCTION,**
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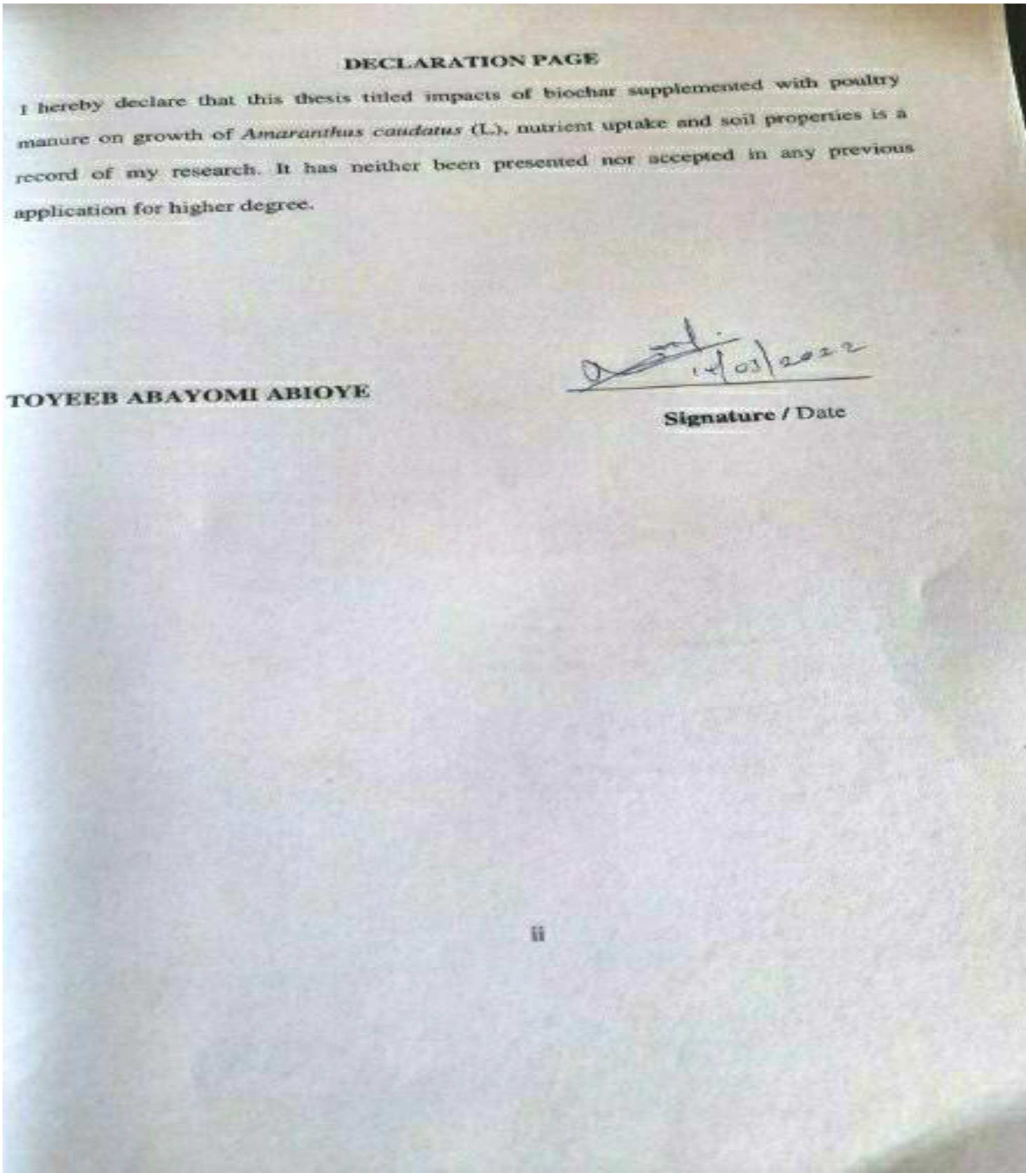

## DECLARATION PAGE

I hereby declare that this thesis titled impacts of biochar supplemented with poultry manure on growth of *Amaranthus caudatus* (L.), nutrient uptake and soil properties is a record of my research. It has neither been presented nor accepted in any previous application for higher degree.

14/03/2022

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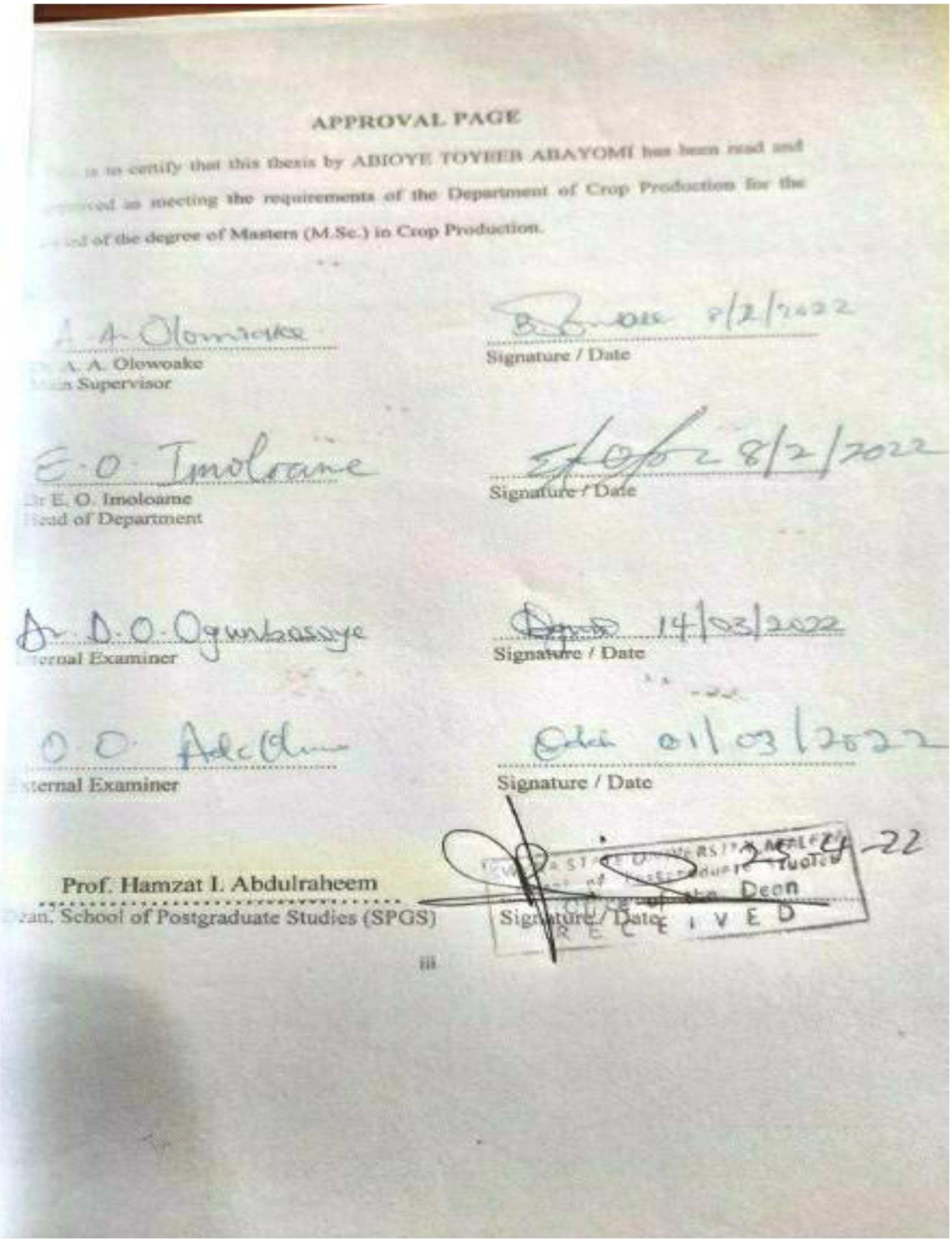

## APPROVAL PAGE

is to certify that this thesis by ABIOYE TOYEEB ABAYOMI has been read and approved as meeting the requirements of the Department of Crop Production for the award of the degree of Masters (M.Sc.) in Crop Production.

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# DEDICATION

This project is dedicated to Almighty Allah, the beneficent the merciful, for His protection and guidance over me since the onset of my birth till this present moment. I give glory and adoration to Him because to Him I belong.

Also to my family and siblings, for their immense contribution towards my success. May Allah grant them their good heart desires (AMEEN). I am forever grateful.

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# Abstract

Biochar application requires fortification for timely plant nutrient release in order to achieve optimum crop performance. The aim of this work was to examine the effects of biochar supplemented with poultry manure on growth and nutrient uptake of *Amaranthus caudatus*, and soil properties. The experiments were carried out in a screenhouse using soil fromfrom Teaching and Research Farm, KWASU Malete and field experiment at National Center for Agricultural Mechanization (NCAM), Idofian, Kwara State in the year 2020. In the screenhouse, nutrient uptake of *Amaranthus caudatus* and soil nutrient changes in biochar supplemented with poultry manure were investigated. *Amaranthus caudatus* was treated with 50 % poultry manure (PM) and 50 % biochar (BC) at 10, 20 and 30 t ha$^{-1}$ including control. Each of the treatments used in the screenhouse as well as NPK 15-15-15 applied at 100 kg N ha$^{-1}$ and control (no fertilizer) were observed in the field experiment. Ratooning of Amaranthus by cutting at 5 cm above the soil line and plant regrowth was assessed in the screenhouse. Residual effects of the treatments used in field experiment was also observed. The study in screenhouse was a completely randomized design with three replicates, why that of the field was a randomized complete block design with three replicates. Plant height, stem girth, number of leaves, fresh and dry yield were observed in the experiments. Pre and post cropping analyses of soils used in screenhouse and field studies were done. Data collected were subjected to statistical analysis (ANOVA). Biochar supplemented with poultry manure at 20 t ha$^{-1}$ significantly enhanced the first planting and regrowth of Amaranthus growth parameters, dry matter yield and nutrient uptake under screenhouse investigation. In the field study, Amaranthus yield value of 8.6 tha$^{-1}$ with 15 t ha$^{-1}$ PM (50 %) + BC (50 %) was significantly ($p < 0.05$) higher than that of NPK treatment (3.6 t ha$^{-1}$) after the first cropping. Residual effect of Amaranthus yield values obtained from 15 t ha$^{-1}$ PM (50 %)+BC (50 %) was also significantly ($p < 0.05$) higher than that of NPK values. PM (50 %) + BC (50 %) at 15 t ha$^{-1}$ had a significant and additive effect on soil nutrients after harvesting of Amaranthus when compared with NPK in first and second cropping. PM (50 %) + BC (50 %) at 15 t ha$^{-1}$ could be used effectively in increasing soil fertility for Amaranthus production.

# CHAPTER ONE

## 1.0 INTRODUCTION

Most Nigerian soils have low nitrogen and the low nitrogen status is usually supplemented with N fertilizer, and the importance of this source has increased over the year (Olowoake and Ojo, 2014). Soil constraints and problems that militate against high crop yields are soil erosion, salinization, flooding, declining fertility, desert encroachment, mismanagement and misuse etc. Conservation and management measures include adoption of minimum tillage, crop rotation, fallowing, fertilization, mulching etc (Akamigbo, 2000).

Major limitation to the usage of chemical fertilizers is due to the adverse effects they have on plant quality and disease susceptibility. A continual dependence on chemical fertilizers may be accompanied by a fall in organic matter content, increased soil acidity, degradation of soil physical properties and increased rate of erosion due to instability of soil aggregates (Adeoluwa and Adeogun, 2010). One of the ways to maintain or improve the soil fertility is by maintaining its organic matter. This is possible through the use of organic sources of fertilizer.

The rapid decomposition of organic matter in the tropics means that nutrient retention is a limiting factor to soil productivity. One emerging management strategy to maintain higher yields is the addition of biochar (Fagbenro and Onawumi, 2013). Biochar is the product of pyrolysis of organic materials in the absence of oxygen and at high temperature. When added to soil, biochar has been reported to increase available nutrients and prevent their leaching, stimulates activity of agriculturally important soil micro-organisms, acts as effective carbon sink for several hundred years, sequester atmospheric $CO_2$ in soil, suppresses emissions of other greenhouse gases and mitigate the detrimental effects of agrochemicals (Thies and Rillig, 2009). While biochar has been shown to have a positive conditioning effect on soil, on its own it may be limited as a nutrient supplier, because of its relatively low nutrient composition and recalcitrance to biodegradation (Partey *et al.*, 2014). Biochar application to soils in combination with either organic or inorganic fertilizer have been reported to have a pronounced effect on plant growth and yield (Chan *et al.*, 2007; Dou *et al.*, 2012). Biochar can effectively retain $NH_3$, $NH_4^+$and $NO_3^-$ in animal manure (Steiner *et al.,* 2010). Recent studies demonstrated that bulking manure with biochar reduced N loss while simultaneously enhancing humification, and producing mature manure with a high fertilizer value (Ishizaki and Okazaki, 2004), thereby increasing the yield of crops. According to Musa *et al*. (2020), biochar and poultry manure when added to soil, boosted the mineralization of the soil after amendment and also improve the growth and yield of tomato. Vegetable production in Africa is as old as peasant farming though its cultivation is still at the household level with very few farmers producing on a commercial level. This could be due to the fact that crops such as cereals, roots, and tubers and body-building crops like legumes are given much attention. Cereals and tubers form the bulk of food consumed in the tropics but they are deficient in minerals and vitamins compared to the body requirement to guarantee good healthy living (Ogunlade *et al.,* 2011). Amaranthus species is a leafy vegetable in the tropical region of world. It forms a high percentage of the daily intake of leafy vegetables (Palada and Chang, 2003). *Amaranthus* *caudatus* is grown for its leaves and is among the highly prized leafy vegetables in Nigeria, due to their high nutritional and commercial significance (Olowoake and Ojo, 2014). Generally, vegetables are widely designated as "protective foods" in human diet due to their varied health benefits attributable to the richness in vitamins, essential fatty acids, minerals, amino acids and dietary fiber (Shukla *et al*., 2016) and various essential bioactive compounds (Da Silva *et al.,* 2017). These include health-promoting plant secondary metabolites composed of antioxidants and phenolic compounds. It is well acknowledged that to meet recommended daily allowance of nutrition, the World Health Organization (WHO) recommended at least 400g of fruit and non-starchy vegetables is used (WHO, 2013).

There is an increasing awareness of value of leaf vegetable in contributing to balanced diet, particularly in area where animal protein is deficient. To grow vegetable Amaranthus, it is necessary to know the effect of sources of nitrogen fertilization on its yield because nitrogen was found to be the primary limiting factors of Amaranthus production (Pospiˇsil *et al.,* 2006). There is little or no research on usage of biochar and poultry manure as soil amendment for Amaranthus growth in Kwara State or Nigeria/Tropics. This study was therefore conducted to examine the effects of biochar enriched with poultry manure on growth of *Amaranthus caudatus*, nutrient uptake and soil properties.

Therefore, the objectives of this study therefore are to:

(a) study the nutrient uptake of *Amaranthus caudatus* and soil nutrient changes in biochar enriched with poultry manure

(b) investigate the effects of biochar supplemented with poultry manure on growth, yield of *Amaranthus caudatus* and soil properties.

(c) evaluate the residual effects of biochar supplemented with poultry manure on the growth, yield of *Amaranthus caudatus* and soil properties.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Biochar as a fertilizer for crop production

Biochar is a charcoal-like substance that's made by burning organic material from agricultural and forestry wastes (also called biomass) in a controlled process called pyrolysis. Although it looks a lot like common charcoal, biochar is produced using a specific process to reduce contamination and safely store carbon. Biochar is a carbon-rich organic material, an organic amendment, and a by-product derived from biomass by pyrolysis under high-temperature and low-oxygen conditions. Biochar is produced through a process called pyrolysis, which basically involves heating of biomass (such as wood, manure, or leaves) in complete or almost complete absence of oxygen, with oil and gas as co-products. However, the quantity of these materials produced depends on the processing conditions. Recently, it has been reported that biochar obtained from the carbonization of organic wastes can be a substitute that not only influences the sequestration of soil carbon but also modifies its physicochemical and biological properties (García *et al*., 2016, Zhang *et al.,* 2017). Biochar has the potential to produce farm-based renewable energy in an eco-friendly way. Specifically, the quality of biochar depends on several factors, such as the type of soil, metal, and the raw material used for carbonization, the pyrolysis conditions, and the amount of biochar applied to the soil (Debela *et al*., 2012). In addition, the biochar amendment to the soil proved to be beneficial to improve soil quality and retain nutrients, thereby enhancing plant growth (Bonanomi *et al*., 2017). Since biochar contains organic matter and nutrients, its addition increased soil pH, electric conductivity (EC), organic carbon (C), total nitrogen (TN), available phosphorus (P), and the cation-exchange capacity (CEC) (Dume *et al.,* 2016). Earlier, Verheijen *et al.* (2009) reported that the biochar application affected the toxicity, transport, and fate of various heavy metals in the soil due to improved soil absorption capacity. The presence of plant nutrients and ash in the biochar and its large surface area, porous nature, and the ability to act as a medium for microorganisms have been identified as the main reasons for the improvement in soil properties and increase in the absorption of nutrients by plants in soils treated with biochar (Nigussie *et al*., 2012). Chan *et al*. (2008) reported that biochar application decreased the tensile strength of soil cores, indicating that the use of biochar can reduce the risk of soil compaction. A lot has already been discussed on the benefits of inoculation of rhizobacteria in soil, but the addition of biochar can also provide more nutrients to the soil, thus benefiting the agricultural crops. The mixing of the plant growth-promoting microorganisms with biochar was referred to as the best combination for growth and yield of French beans by Saxena *et al*. (2013).

### 2.1.1 Biochar production and properties

Biochar is made up of elements such as carbon, hydrogen, sulfur, oxygen, and nitrogen as well as minerals in the ash fraction. It is produced during pyrolysis, a thermal decomposition of biomass in an oxygen-limited environment. Biochar is black, highly porous, and finely grained, with light weight, large surface area and pH, all of which have a positive effect on its application to soil. To address the major concern on quality of agricultural soil degradation, biochar is applied to the soil in order to enhance its quality. Biochar is stabilized biomass, which may be mixed into soil with intentional changes in the properties of the soil's atmosphere to increase crop productivity and to mitigate pollution. The raw material (biomass) used and processing parameters dictate the properties of the biochar.

### 2.1.2 Biomass as a raw material

A wide range of organic materials are suitable as feedstock for the production of biochar. Biochar can be produced with raw materials such as grass, cow manure, wood chips, rice husk, wheat straw, cassava rhizome, and other agricultural residues (Ronsse *et al.*, 2013, Kiran *et al.,* 2017). It was reported that the production of biochar with high nutrients depends on the type of raw material used and pyrolysis conditions (Chan *et al.,* 2007). Biochar is produced from the residual biomasses such as crop residues, manure, wood residues, and forests and green wastes using modern pyrolysis technology. Agricultural wastes (bark, straw, husks, seeds, peels, bagasse, sawdust, nutshells, wood shavings, animal beds, corn cobs and corn stalks, etc.), industrial wastes (bagasse, distillers' grain, etc.), and urban/municipal wastes (Novotny *et al.,* 2015, Kameyama *et al.,* 2016) have been extensively used, thus also achieving waste management through its production and use (Woolf *et al.,* 2010). Feedstocks currently used on a commercial scale include tree bark, wood chips, crop residues (nut shells, straw, and rice hulls), grass, and organic wastes including distillers' grain, bagasse from the sugarcane industry, mill waste, chicken litter, dairy manure, sewage sludge, and paper sludge (Tumuluru *et al.*, 2011, Sohi *et al.*, 2009, Reddy, 2015). A 40 wt.% yield of biochar from maize stover was obtained by Peterson *et al.*, (2012). The biomass used for the production of biochar is mainly composed of cellulose, hemicellulose, and lignin polymers (Sullivan *et al.*, 2012). Among these, cellulose has been found to be the main component of most plant-derived biomasses, but lignin is also important in woody biomass.

### 2.1.3 Biochar production

Biochar can be manufactured on a small scale using low-cost modified stoves or kilns or through large-scale, cost-intensive production, which utilizes larger pyrolysis plants and higher amounts of feedstocks. Biochar is produced from several biomass feedstocks through pyrolysis as discussed above, generating oil and gases as by-products (Zhu *et al.*, 2018). The dry waste obtained is simply cut into small pieces to less than 3 cm prior to use. The feedstock is heated either without oxygen or with little oxygen at the temperatures of 350–700°C (662–1292°F). Pyrolysis is generally classified by the temperature and time duration for heating; fast pyrolysis takes place at temperatures above 500°C and typically happens on the order of seconds (heating rates ≥ 1000°C/min). This condition maximizes the generation of bio-oil. Slow pyrolysis, on the other hand, usually takes more time, from 30 min to a few hours for the feedstock to fully pyrolyze (heating rates ≤ 100°C/min) and at the same time yields more biochar. The temperature range remains 250–500°C (Brown *et al.*, 2011).

The type of biochar produced depends on two variables: the biomass being used and the temperature and rate of heating. High and low temperatures have an unequivocal effect on char yields. It has been noticed that at low temperature (<550°C), biochar has an amorphous carbon structure with a lower aromaticity than the biochar produced at high temperature (Joseph *et al.*, 2010). High temperature leads to lower char yield in all pyrolysis reactions (Antal *et al.,* 2003). Peng *et al*. (2011) reported the effect of charring duration on the yield of biochar; yield showing a decrease with increasing duration at the same temperature. The pyrolysis process seriously affects the quality of biochar and its potential value to agriculture in terms of agronomic performance or in carbon sequestration. The yield of biochar from slow pyrolysis of biomass has been stated to be in the range of 24–77% (Dutta, 2010, Stoyle, 2011) (Figure 1). The pyrolysis process can be shown as follows:

Biomass(Solid)→Biochar+Liquid or oil (tars, water, etc.)+Volatile gases (CO2,CO,H2)

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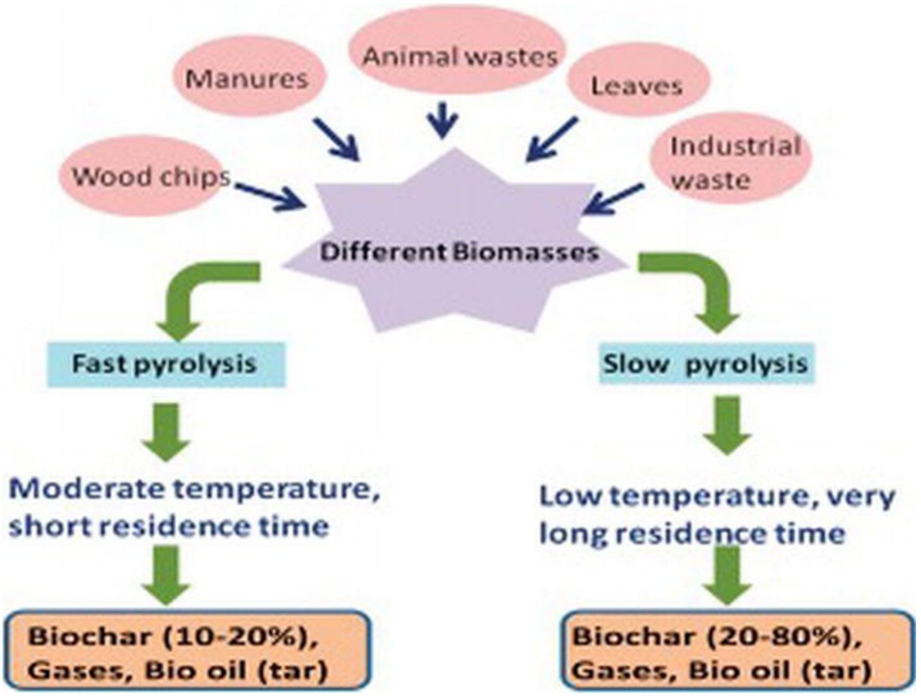

**Figure 1.** Biochar production from different biomasses.

Source: Dutta, (2010) and Stoyle, (2011).

### 2.1.4 Physical, chemical and biological properties of biochar

Biochar is a stable form of carbon and can last for thousands of years in the soil (Shenbagavalli *et al.*, 2012). It is produced for the purpose of addition to soil as a means of sequestering carbon and improving soil quality. The conditions of pyrolysis and the materials used can significantly affect the properties of biochar. The physical properties of biochar contribute to its function as a tool for managing the environment. It has been reported that when biochar is used as a soil amendment, it stimulates soil fertility and improves soil quality by increasing soil pH, increasing the ability to retain moisture, attracting more useful fungi and other microbes, improving the ability of cation exchange, and preserving the nutrients in the soil (Ajema, 2018). Biochar reduces soil density and soil hardening, increases soil aeration and cation-exchange capacity, and changes the soil structure and consistency through the changes in physical and chemical properties. It also helps to reclaim degraded soils. It has shown a greater ability to adsorb cations per unit carbon as compared to other soil organic matters because of its greater surface area, negative surface charge, and charge density (Liang *et al.*, 2006), thereby offering the possibility of improving yields (Lehmann, 2007).

Samples with a sufficient amount of stable carbon can be added to the soil to be sequestered; a high sorption surface of biochar can characterize it as a soil additive, competent of halting risk elements in soil. The physical characteristics of biochar are directly and indirectly related to how they affect soil systems. Soils have their own physical properties depending on the nature of mineral and organic matter, their relative amounts, and how minerals and organic matter are related. When biochar is present in the soil mixture, its contribution to the physical nature of the system is significant, affecting the depth, texture, structure, porosity, and consistency by changing the surface area, pore and particle-size distribution, density, and packing (Blanco-Canqui, 2017). The influence of biochar on physical properties of soil directly affects the growth of plants, since the depth of penetration and accessibility of air and water in the root zone is determined mainly by the physical composition of the soil horizons. This affects the soil's response to water, its aggregation, and work ability in soil preparation, dynamics, and permeability when swelling, as well as the ability to retain cations and response to changes at ambient temperature. The smaller the pores on biochar, the longer they can retain capillary soil water. The addition of biochar can reduce the effects of drought on crop productivity in drought-affected areas due to its moisture-retention capacity. It has been shown that it eliminates soil constraints that limit the growth of plants, and neutralizes acidic soil because of its basic nature (Hammes *et al*., 2008). Carbon dioxide and oxygen occupy air-filled spaces on the pores of biochar or can be chemosorbed on the surface. As biochar can contain nutrients, microorganisms, and syngases, it can also retain fertilizers in the soil longer than other soils and prevent it from leaching into water sources such as rivers and lakes. As far as its chemical properties are concerned, biochar reduces soil acidity by increasing the pH (also called the liming effect) and helps the soil to retain nutrients and fertilizers (Lehmann *et al*., 2006).

The application of biochar improves soil fertility through two mechanisms: adding nutrients to the soil (such as K, to a limited extent P, and many micronutrients) or retaining nutrients from other sources, including nutrients from the soil itself. However, the main advantage is to retain nutrients from other sources. In most cases, the addition of biochar only has a net positive effect on the growth of crops if nutrients from other sources, such as inorganic or organic fertilizers, are used. Biochar increases the availability of C, N, Ca, Mg, K, and P to plants, because biochar absorbs and slowly releases fertilizers (DeLuca *et al*., 2015). It also helps to prevent fertilizer drainage and leaching by allowing less fertilizer use and reducing agricultural pollution in the surrounding environment (Cao *et al.,* 2018). Biochar alleviates the impact of hazardous pesticides and complex nitrogen fertilizers from the soil, thus reducing the impact on the local environment. Good healthy soil should include a wide and balanced variety of life forms, including bacteria, fungi, protozoa, nematodes, arthropods, and earthworms. Recently, biochar has been reported to increase the microbial respiration of the soil by creating space for soil microbes (Slapakova *et al*., 2018), and in turn the soil biodiversity and soil density increased. Biochar also served as a habitat for extra-radical fungal hyphae that sporulated in micropores due to lower competition from saprophytes and therefore served as an inoculum for arbuscular mycorrhizal fungi (Saito *et al*., 2002). It is believed that biochar has a long average dwelling time in soil, ranging from 1000 to 10,000 years, with an average of 5000 years (Skjemstad *et al*., 1998, Swift, 2001, Krull *et al.,* 2003). However, its recalcitrance and physical nature present significant impediment to the evaluation of long-term stability (Lehmann, 2007). The commercially available soil microbes which can be used for inoculation include *Azospirillum* sp., *Azotobacter* sp., *Bacillus thuringiensis*, *B. megaterium*, *Glomusfasciculatum*, *G. mosseae*, *Pseudomonas fluorescens*, *Rhizobium* sp., and *Trichodermaviride* (Hazarika *et al*., 2007).

### 2.1.5 Biochar as a soil amendment

The issues as food security, declining soil fertility, climate change, and profitability are the driving forces behind the introduction of new technologies or new farming systems. The amendment of soils for their remediation aims at reducing the risk of pollutant transfer to waters or receptor organisms in proximity. The organic material such as biochar may serve as a popular choice for this purpose because its source is biological and it may be directly applied to soils with little pretreatment (Beesley *et al*., 2011). There are two aspects which make biochar amendment superior to other organic materials: the first is the high stability against decay, so that it can remain in soil for longer times providing long-term benefits to soil and the second is having more capability to retain the nutrients. Biochar amendment improves soil quality by increasing soil pH, moisture-holding capacity, cation-exchange capacity, and microbial flora (Mensah *et al*., 2011). The addition of biochar to the soil has shown the increase in availability of basic cations as well as in concentrations of phosphorus and total nitrogen (Glaser *et al.,* 2002, Lehmann *et al*., 2003). Typically, alkaline pH and mineral constituents of biochar (ash content, including N, P, K, and trace elements) can provide important agronomic benefits to many soils, at least in the short to medium term. When biochar with a higher pH value was applied to the soil, the amended soil generally became less acidic (Yuan *et al*., 2011). Acidic biochar could also increase soil pH when used in soil with a lower pH value. The pH of biochar, similar to the other properties, is influenced by the type of feedstock, production temperature, and production duration. Another valuable property of biochar is suppression of emissions of greenhouse gases in soil. It has also been demonstrated by Zhang *et al*. (2010) that the emissions of methane and nitrous oxide were reduced from agricultural soils, which may have additional climate mitigation effects, since these are potent greenhouse gases. Spokas *et al*. (2009) reported reduced carbon dioxide production by addition of different concentrations of biochar ranging from 2 to 60% (w/w), suppressed nitrous oxide production at levels higher than 20% (w/w), and ambient methane oxidation at all levels over un-amended soil. Several studies have shown the control of pathogens by the use of biochar in agricultural soil. Bonanomi *et al*. (2015) reported that biochar is effective against both air-borne (e.g. *Botrytis cinerea* and different species of powdery mildew) and soil-borne pathogens (e.g. *Rhizoctonia solani* and species of *Fusarium* and *Phytophthora*). The application of the biochar derived from citrus wood was capable of controlling air-borne gray mold, *Botrytis cinerea* on *Lycopersicon esculentum*, *Capsicum annuum* and *Fragaria* × *ananassa*. Although there is a shortage of published data on the effects of biochar on soil-borne pathogens, evidence given by Elmer *et al*. (2010) has shown that the control of certain pathogens may be possible. The addition of biochar in 0.32, 1.60, and 3.20% (w/w) to asparagus soils infested with *Fusarium* has augmented the biomass of asparagus plants and reduced *Fusarium* root rot disease (Elmer *et al*., 2010). Similarly, *Fusarium* root rot disease in asparagus was also reduced by biochar inoculated with mycorrhizal fungi (Thies *et al*., 2015). A study of suppression of bacterial wilt in tomatoes showed that biochar obtained from municipal organic waste reduced the incidence of the disease in *Ralstonia solanacearum* infested soil (Nerome *et al*., 2005). Ogawa, (2009) advocated the use of biochars and biochar amended composts for controlling the diseases caused by bacteria and fungi in soil. The disease suppression mechanism has been attributed to the presence of calcium compounds, as well as improvements in the physical, chemical, and biological characteristics of the soil. The prevention of 'diffuse water pollution' through ammonium sorption or the mediation of the dynamics of a soil solution containing nitrate, phosphorus, and other nutrients has been extensively studied. The application of biochar to soil can influence a wide range of soil constraints such as high availability of Al (van Zwieten *et al*., 2010), soil structure and nutrient availability (Chan *et al*., 2007), bioavailability of organic (Yu *et al*., 2009) and inorganic pollutants (Hua *et al*., 2009), cation-exchange capacity (CEC), and retention of nutrients (Major *et al*., 2010, Singh *et al*., 2010). Biochar can also adsorb pesticides, nutrients, and minerals in the soil, preventing the movement of these chemicals into surface water or groundwater and the subsequent degradation of these waters from agricultural activity. Xie *et al*. (2013) reported that biochar amendment enhanced soil fertility and crop production, particularly in soils with low nutrients. However, in soils with high fertility, no noticeable increase in production was noticed, and some studies even reported inhibition of plant growth. The observations of Taghizadeh-Toosi *et al*. (2012) indicated that ammonia adsorbed by biochar could be later released to the soil. Saarnio *et al*. (2013) showed that biochar application along with fertilizers can lead to better plant growth, but sometimes a negative effect was also observed without fertilization due to reduced bio-availability through sorption of nitrogen. It has been shown that application of biochar in the soil has a positive to neutral and even negative impact on crop production. Hence, it is crucial that the mechanisms for action of biochar in the soil be understood before its application. The consequence of biochar addition on plant productivity depends on the amount added. Recommended application rates for any soil amendment should be based on extensive field testing. At present, insufficient data are available for obtaining general recommendations. In addition, biochar materials can vary greatly in their characteristics, so the nature of the particular biochar material (e.g. pH and ash content) also influences the application rate. Several studies have reported a positive effect of using biochar on crop yields with rates of 5–50 tonnes per hectare with appropriate nutrient management. The experiments conducted by Rondon *et al*. (2007) resulted in a decrease in crop yield in a pot experiment with nutrient deficient soil amended with biochar at the rate of 165 tonnes per hectare. An experiment conducted in the United States showed that peanut hull and pine chip biochar, applied to 11 and 22 tonnes per hectare, could reduce corn yields below those obtained in the control plots with standard fertilizer management (Gaskin *et al*., 2010). Thus, the control of the rate of application of biochar is necessary to prevent the negative impact of biochar.

### 2.1.6 Stimulation of soil microflora and plant growth

There are several reports which show that biochar has the capability to stimulate the soil microflora, which results in greater accumulation of carbon in soil. Besides adsorbing organic substances, nutrients, and gases, biochars are likely to offer a habitat for bacteria, actinomycetes and fungi (Thies *et al*., 2015). It has been suggested that faster heating of biomass (fast pyrolysis) will lead to the formation of biochar with fewer microorganisms, smaller pore size, and more liquid and gas components (Nartey and Zhao, 2014). The enhancement of water retention after biochar application in soil has been well established (Busscher *et al.,* 2010), and this may affect the soil microbial populations. Biochar provides a suitable habitat for a large and diverse group of soil microorganisms, although the interaction of biochar with soil microorganisms is a complex phenomenon. Many studies reported that addition of biochar along with phosphate solubilizing fungal strains promoted growth and yield of *Vignaradiata* and *Glycine max* plants, with better performances than control or those observed when the strains and biochar are used separately (Saxena *et al*., 2013, Saxena *et al*., 2016, Saxena *et al.,* 2017).The use of biochar increased mycorrhizal growth in clover bioassay plants by providing the suitable conditions for colonization of plant roots (Solaiman *et al*., 2010). Warnock *et al.* (2007) summarized four mechanisms by which biochar can affect functioning of mycorrhizal fungi: (i) changes in the physical and chemical properties of soil, (ii) indirect effects on mycorrhizae through exposure to other soil microbes, (iii) plant-fungus signaling interference and detoxification of toxic chemicals on biochar, and (iv) providing shelter from mushroom browsers. Carrots and legumes grown on steep slopes and in soils with less than 5.2 pH showed significantly improved growth by the addition of biochar (Rondon *et al.,* 2004). It was found that biochar increased the biological $N_2$ fixation (BNF) of *Phaseolus vulgaris* (Rondon *et al.,* 2007) mainly due to greater availability of micronutrients after application of biochar. Lehmann *et al.* (2003) reported that biochar reduced leaching of $NH_4^+$ by supporting it in the surface soil where it was available for plant uptake. Mycorrhizal fungi were often included in crop management strategies as they were widely used as supplements for soil inoculum (Schwartz *et al.,* 2006). When using both biochar and mycorrhizal fungi in accordance with management practices, it is obviously possible to use potential synergism that can positively affect soil quality. The fungal hyphae and bacteria that colonize the biochar particles (or other porous materials) may be protected from soil predators such as mites, Collembola and larger (>16 μm in diameter) protozoans and nematodes (Saito, 1990, Pietikainen *et al.,* 2000, Ezawa *et al.,* 2002).

Biochar can increase the value of non-harvested agricultural products (Major *et al.,* 2005) and promote the plant growth (Lehmann *et al*., 2003, Oguntunde *et al*., 2004). A single application of 20 t $ha^{-1}$ biochar to a Colombian savanna soil resulted in an increase in maize yield by 28–140% as compared with the unamended control in the 2nd to 4th years after application (Major *et al.,* 2010). With the addition of biochar at the rate of 90 g $kg^{-1}$ to tropical, low-fertile ferralsol, not only the proportion of N fixed by bean plants (*Phaseolus vulgaris*) increased from 50% (without biochar) to 72%, but also the production of biomass and bean yield were improved significantly (Rondon *et al*., 2007). When biochar was applied to the soil, a higher grain yield of upland rice (*Oryza sativa*) was obtained in northern Laos sites with low P availability (Asai *et al*., 2009, Silber *et al*., 2010). Many of these effects are interrelated and may act synergistically to improve crop productivity. Often there has been a reported increase in yields, which is directly related to the addition of biochar as compared to the control (without biochar) (Lehmann *et al*., 2003).

The direct beneficial effects of biochar addition for the availability of nutrients are largely due to the higher content of potassium, phosphorus, and zinc availability and, to a lesser extent, calcium and copper (Lehmann *et al*., 2003). Few studies have examined the potential for amending biochar in soil to impact plant resistance to pathogens. With reference to soil pathogens principally concerned with the effect of AM fungal inoculations on asparagus tolerance to the soil borne root rot pathogen *Fusarium*, Matsubara *et al.* (2002) demonstrated that charcoal amendments had a suppressive effect on pathogens. One more study that supported these earlier findings stated that biochar made from ground hardwood added to asparagus field soil led to a decrease in root lesions caused by *Fusarium oxysporum*, *F. asparagi,* and *F. proliferatum* compared to the non-amended control (Elmer and Pignatello, 2011). Biochar reduces the need for fertilizer, which results in reduction in emissions from fertilizer production, and turning the agricultural waste into biochar also reduces the level of methane (another potent greenhouse gas) caused by the natural decomposition of waste.

### 2.1.7 Mixing biochar with other amendments

Mixing biochar with other soil amendments such as manure, compost, or lime before soil application can improve efficiency by reducing the number of field operations required. Since biochar has been shown to sorb nutrients and protect them from leaching (Major *et al*., 2010, Novak *et al*., 2009), mixing of biochar may improve the efficiency of manure and other amendments. However, Kammann *et al.* (2016) acknowledged in their recent review that very few studies that directly combined organic amendments with biochars were available. They found that co-composted biochars had a remarkable plant growth-promoting effect as compared to biochars when used pure, but no-systematic studies have been done to understand the interactive effects of biochars with non-pyrogenic organic amendments (NPOAs). Biochar can also be mixed with liquid manures and used as slurry. Additionally, combined biochar and compost applications have numerous advantages over mixing of biochar or compost with soil separately. These benefits, according to Liu *et al.* (2012), include more efficient use of nutrients, biological activation of biochar, an enhanced supply of plant-available nutrients by biological nitrogen fixation, reduction of nutrient leaching, and the contribution of combined nutrients in comparison to a single application of compost and biochar. Diminutive biochars are most likely best suited for this type of application. Biochar was also mixed with manure in ponds and potentially reduced losses of nitrogen gas were recorded same as when it was applied to soil (Yanai *et al.*, 2007, Spokas *et al.,* 2009).Addition of biochar in the soil can be extremely useful to improve the soil quality, as well as to stimulate the plant growth, and thus, biochar can play an important role in developing a sustainable system of agriculture. Several uses and positive effects of biochar amendment have currently been considered as an effective method to reclaim the contaminated soil (Placek *et al.,* 2016) and to achieve high crop yields without harming the natural environment. The positive influence of biochar on plant growth and soil quality suggests that using biochar is a good way to overcome nutrient deficiency, making it a suitable technique to improve farm-scale nutrient cycles. Therefore, a complete focus is been made to explore the positive effects of biochar amendment on soil stability and plant growth promotion.

## 2.2 Poultry Manure as a fertilizer for crop production

### 2.2.1 Poultry Manure and its effect on soil properties

Poultry manure is the feces of poultry birds used as an organic fertilizer, especially for soil low in nitrogen (Telkamp, 2015).Of all animal manures, it has the highest amount of nitrogen, phosphorus, and potassium (Deborah and Grace, 1992). Poultry manure is sometimes pelletized for use as a fertilizer, and this product may have additional phosphorus, potassium or nitrogen added (Barrett, 2008). Optimal storage conditions for poultry manure include keeping it in a covered area and retaining its liquid, because a significant amount of nitrogen exists in the urine (Pullin and Shehadeh, 1980).The main reasons for applying poultry manure includes condition of the soil and the provision of nutrients to crops (Evers, 2002). Poultry manure supplies more phosphorous to plants than other organic manure sources (Garg and Bahla, 2008). Poultry manure is usually richer in nitrogen than other livestock manure because birds have a common duct for the elimination of urine and faeces. It also improves soil physical and chemical properties such as increased porosity and moisture content which contribute to root growth and grain yield (Agbede *et al.,* 2008). Therefore, poultry manure is a major source of nutrients for crops. Fresh poultry manure contains 0.5% (Ecochem, 2016) to 0.9% nitrogen (Foreman and Long, 2013)*,* 0.4% (Pullin and Shehadeh, 1980) to 0.5% phosphorus (Ecochem, 2016), and 1.2% to 1.7 %potassium (Ecochem, 2016). One chicken produces approximately 8–11 pounds of manure monthly (Foreman and Long, 2013). Poultry manure can be used to create homemade plant fertilizer (Foreman and Long, 2013).Poultry manure has been used as a soil amendment to sustain adequate crop yield (Adeleye *et al.,* 2010). It can be applied on the soil surface for pastures and no till fields or incorporated into the soil in conventional-till fields as a fertilizer (Doydora *et al.,* 2011). According to Mbah *et al.* (2006), application of organic manure improves and ameliorates several soil physical properties such as bulk density, total porosity, penetration resistance and cohesion force. Poultry manure has long been recognized as a valuable fertilizer for pasture and forage production (Olatunji *et al.,* 2012) and is known to have high organic carbon content which adds organic matter to the soil (Boateng *et al.,* 2006). Poultry manure is also very cheap and effective as a source of N for sustainable crop production (Khalid *et al.,* 2014). Disposal of poultry manure traditionally includes its utilization as fertilizer, but its improper application and / or overuse represents potential environment problems, such as spread of pathogens (Gerber *et al.,* 2005) and emission of greenhouse gasses and odorous compounds. Nitrogen present in poultry manure can be converted to ammonia and nitrates. Leaching of soluble nutrients can cause ground water pollution and favour high levels of nitrate in drinking water. These high levels of $NO_3$ can cause cancer, respiratory disease in humans, foetal abortion in livestock and methoemoglobinaemia, a blood disorder in infants commonly known as “blue baby disease” (Henihan *et al.,* 2003). Furthermore, ammonia emissions are environmentally harmful through nitrogen return in rain and they produce highly climate-damaging emissions of nitrous oxide, soil acidification and eutrophication of water bodies (Gerlach and Schmidt, 2012). However, addition of biochar can significantly minimize these problems.

### 2.2.2 Effects of poultry manure on soil physical properties

#### 2.2.2.1 Effects of poultry manure on bulk density

The addition of poultry manure to soil reduces soil bulk density (Adeleye *et al.,* 2010) because poultry manure promotes aggregation which thereby results in more space and lower density. A decrease in soil bulk density was also reported by Ojeniyi *et al.* (2013) after applying different rates of poultry manure at 2.5, 5.0, 7.5 and 10t/ha where bulk densities were decreased by 4.3, 13.9, 22.9 and 31.3%, respectively. It can be concluded that some researchers found that bulk density values were only slightly lowered by manure application (from 1.57 to 1.55-1.53 Mg $m^{-3)}$ (Boateng *et al.,* 2006) implying that application of poultry manure had a slight impact on bulk density. A decrease in soil bulk density can be associated with an increase in total porosity and moisture content (Agbede *et al.,* 2008). In contrast, researchers such as Aluko and Oyedele, (2005) found that poultry manure incorporation had no significant effect on soil density. More in-depth and long term in situ studies are needed to confirm the importance of poultry manure on soil bulk density alteration.

#### 2.2.2.2 Effects of poultry manure on aggregate stability

Aggregate stability is a keystone factor in question of soils fertility and environmental problems (Olatunji *et al.,* 2012). Aggregate stability increases with increasing rate of poultry manure application (Olatunji *et al.,* 2012) and more significant result of increase aggregate stability due to poultry manure application can be observed after a long period (Khalid *et al.,* 2014). It has also been indicated that the addition of organic matter to soil could have positive or negative effect on aggregate stability (Spaccini *et al.,* 2001).

### 2.2.3 Effects of poultry manure on soil chemical properties

#### 2.2.3.1 Effects of poultry manure on soil nutrients

Poultry manure offers an inexpensive fertilizer source particularly for nitrogen and phosphorous because it has been known to contain more nutrient than other manures (Duncan, 2005). Poultry manure has been identified as a potentially available slow – release nutrient source for crops (Agblevor *et al.,* 2010). The release of these nutrients from the manure is increased when the soil provides warm, moist conditions, favourable for microbial decomposition. Application of poultry manure on soil improves soil OM, N, P, K, Ca, and Mg (Kingery *et al.,* 1993; Adeniyan and Ojeniyi 2005; Akanbi *et al.,* 2005; Adenawoola and Adejoro, 2005).

## 2.3 Interaction of biochar and poultry manure in soil

Biochar and poultry manure are mostly known to positively affect soil properties and plant production. The use of poultry manure ensures the stability of soil structure, improve soil organic matter status, nutrient availability and high crop yield (Adeleye *et al.,* 2010), while on the other hand, biochar application improves soil tilth, production, nutrient retention and availability, improves water holding capacity and aggregate stability (Glaser *et al.,* 2002). Limited research has been conducted to investigate the interaction of biochar and poultry manure on soil, and how the use of a combination of biochar and poultry manure will affect soil properties, nutrient availability and crop yield.

## 2.4 AMARANTHUS PRODUCTION

### 2.4.1 Taxonomy of Amaranthus

*Amaranthus* species belong to the *Caryophyllales* order, *Amaranthaceae* family, *Amaranthoideae* subfamily, and *Amaranthus* genus (Montoya-Rodríguez *et al.,* 2015; Mlakar *et al.,* 2009). The *Caryophyllales* contains 33 families, 692 genera, and 11,155 species. The taxonomic classification of the *Amaranthaceae* has been studied intensively and genetic research revealed that morphological and anatomical characters are different from phylogenetic relationships (Kadereit *et al.,* 2003). The two subfamilies; *Amaranthoideae* and *Chenopodioidea* are closely related, and for a long time were considered as one evolutionary line due to their morphological similarities. *Chenopodiaceae* and *Amaranthaceae* together, have been separated based on three characters: stamen connation, sepal fleshiness, and sepal color, but there are numerous exceptions to these subfamilies (*Amaranthoideae, Betoideae, Camphorosmoideae, Chenopodioideae, Corispermoideae, Gomphrenoideae, Polycnemoideae, Salicornioideae, Salsoloideae, Suaedoideae*) with 180 genera (including *Amaranthus*) and 2500 species (Pratt, 2003; Müller *et al.,* 2005). The genus *Amaranthus* has been the subject of many taxonomic studies, but it is still classed as "difficult." The taxonomy is complicated by numerous hybrid forms, a wide geographical distribution, and small and difficult to recognize diagnostic elements (Assad *et al.,* 2017). The *Amaranthus* genus includes around 60 species of which 40 are native to the Americas and the rest to Africa, Asia, and Europe (Zhigila *et al.,* 2014) with 17 species with edible leaves and 3 grain amaranths (Costea and

DeMason, 2001). Seventy-five species were reported by Sauer (1993), 123 are reported by the United States Department of Agriculture (USDA), National Plant Germplasm System, and 100 are reported in the Hanf study (as cited in Assad *et al.,* 2017, followed by Jacobsen *et al.* (2003), report 87 species, of which 14 are recognizable in Australia, 17 in Europe, and 56 in America.

Sauer's (1967) taxonomic key listed three (3) principal species of *Amaranthus*, for grain production:

- *Amaranthus caudatus* L.
- *Amaranthus hypochondriacus* L.
- *Amaranthus cruentus* L.

The USDA presents the following taxonomic classification of *A. caudatus*:

- Kingdom: *Plantae*
- Subkingdom: *Tracheobionta*
- Superdivision: *Spermatophyta*
- Division: *Magnoliophyta*
- Class: *Magnoliopsida*
- Subclass: *Caryophyllidae*
- Order: *Caryophyllales*
- Family: *Amaranthaceae*

- Genus: *Amaranthus* L.
- Species: *Amaranthus caudatus* L.

### 2.4.2 Origin and distribution

The origin of *A. caudatus* remains uncertain. It is generally believed that it originated in South America or Central America from some unspecified wild race of the *A. hybridus* aggregate, probably South American *A. quitensis* (Flora of North America Editorial Committee, 2016). This species is cultivated elsewhere except cold-temperate, subarctic and arctic zones (Flora of North America Editorial Committee, 2016). However, cultivation of this pseudocereal is declining in South America (Coons, 1982).

*Amaranthus caudatus* is one of the most popular domesticated amaranths and is cultivated primarily as an ornamental and to a lesser degree, as a pseudocereal. This species may occur locally, usually close to places of cultivation and mostly in the southern regions. No reliable records of their successful naturalization are available. It is impossible at present to trace records of such ephemeral populations and individual escapes (Flora of North America Editorial Committee, 2016). In Nigeria *Amaranthus caudatusis* introduced and present only in captivity/cultivation. (Mathai *et al.,* 1981).

### 2.4.3 Botany/Morphology of *Amaranthus caudatus*

Annual herb, erect, to 1.5 m tall, commonly reddish or purple throughout; stems and leaves glabrous or more or less sparingly pilose; leaves long-petiolate, lamina broadly ovate to rhomboid-ovate or ovate-elliptic. 2.5-15 cm long. 1-8 cm broad, obtuse to subacute at the mucronulate apex, shortly cuneate at base, flowers in axillary or terminal red or green spikes formed of cymose clusters, the terminal inflorescence often tail-like, pendulous spike to 30 cm or more long; bracts and bracteoles deltoid-ovate, acuminate, with a rigid arista; perianth segments 5; capsule 2-2.5 mm long, ovoid-globose, circumsessile; seeds black, shiny (Liogier, 1985). *A. caudatus is an*annual, herbaceous plant type

### 2.4.4. Genetics

*Amaranthus caudatus* shows wide genetic variation and diversity of plant form, ranging from erect to completely decumbent. Two types have been distinguished: subsp. *caudatus*, the main type and subsp. *mantegazzianus*, grown as a grain crop in the valleys of the Andes in north-western Argentina. The latter can be distinguished by its determinate club-shaped inflorescence branches, due to a single recessive gene. According to some, it should be considered as a separate species *A. mantegazzianus*, an opinion which is supported by the results of seed protein studies (Agong, 2006).

### 2.4.5. Reproductive Biology

Reproduction is by seed, flowering occurs in summer-autumn (Flora of North America Editorial Committee, 2016).

### 2.4.6 Physiology and Phenology

Germination of *A. caudatus* seed accelerates with increasing temperature in the range 5-35°C; no germination occurs at 0°C. Seedlings normally emerge 3-5 days after sowing and early growth is slow. Flowering begins 60-110 days after emergence. Outcrossing rates of 6-29% have been recorded in *A. caudatus*. The total crop duration in Peru ranges from 3-4 months at an altitude of 1800 m, to 9 months at an altitude of 3200 m; in Kenya it is normally 80-90 days. A single plant may yield more than 50,000 seeds. *A. caudatus* is a C4-cycle plant, giving higher yields at higher light intensities and temperatures and being efficient in water use (Agong, 2006).

### 2.4.7 Longevity

*Amaranthus caudatus* is a bushy, erect annual (PFAF, 2019) or biennial (Royal Horticultural Society, 2021).

### 2.4.8 Environmental Requirements

In the tropics, *A. caudatus* performs well under cool, dry highland conditions. It is more tolerant to chilling than the other two grain amaranths and is grown at higher altitudes. In East Africa, it is found at altitudes of 500-2500 m; in South America at 1000-3200 m. In Peru, it is grown in regions with an average annual rainfall of 550 mm. The photoperiodic response is marked, with flowering being promoted by short photoperiods. *A. caudatus* can be grown in sandy and clay soils. In general, grain amaranths prefer well-drained neutral or alkaline soils (pH>6), but some types are well adapted to acid and mildly saline soils (Agong, 2006).

### 2.4.9 Importance of *Amaranthus caudatus*

*Amaranthus caudatus* seeds are toasted and popped, ground into flour or boiled for gruel. For making leavened foods, they must be blended with wheat (*Triticum aestivum*)**.** The seeds are fermented to make alcoholic beverages, e.g. beer ('tella') in Ethiopia. In Ethiopia, cooked seeds are made into porridge and ground seeds are mixed with tef (*Eragrostistef*) to prepare pancake-like bread ('injera'). Seeds can be sprouted for use as a nutritious vegetable. The leaves are eaten as a vegetable like those of other amaranth species, e.g. in Peru and Ethiopia. Harvest residues are used for feeding livestock and for thatching. In South America, grain amaranths are traditionally used in medicine, folk festivals and as dye sources (Agong, 2006).

### 2.4.10 Economic Value

No statistics are available on production and trade of grain amaranths in general and ***A***. *caudatus* in particular. Reports from the 1990s mention several thousand hectares of grain amaranths in China, similar large production areas in Argentina and about 2000 ha in the United States. Estimates for India and Nepal are up to 4000 ha. In Peru, there are over 1000 ha of grain amaranths (mainly *A. caudatus*) in the high Andean region alone. The United States imports large quantities of grain amaranth from Mexico (Agong, 2006).

### 2.4.11 Social Benefit

The roots, leaves and seeds of *A. caudatus* are used as natural remedies (Hong Kong Baptist University, 2007; Martinez-Lopez *et al.*, 2020). Several studies have highlighted the importance of *A. caudatus* as a potential source of biologically active compounds with anti-pyretic, anti-diabetic, anti-hyperlipidaemic, and anti-hypercholesterolaemic effects and antioxidant and antimicrobial activities (Girija *et al.*, 2011; Kumar *et al.,* 2011; Kumar *et al.*, 2013; Preeth and Das, 2014).In Ethiopia, the root of *A. caudatus* is used as a laxative and the seed for expelling tapeworms and for treating eye diseases, amoebic dysentery and breast complaints. In India, the plant is taken as a diuretic and applied to sores (Agong, 2006).

### 2.4.12 Nutrient Content

Amaranthus *caudatus* is a rich source of iron (72–174 mg/L), calcium (1300–2850 mg/L), magnesium (2300–3360 mg/L) and zinc (36.2–40 mg/L) (Gamel *et al*., 2005). Amaranth has shown better amount of calcium, phosphorus and iron than rice and maize, and a comparable amount of iron in wheat (Nascimento *et al*., 2014).

### 2.4.13 Production challenges

Crop growth and productivity are strongly influenced by various biotic and abiotic stresses such as pests, weeds, drought, high salinity, extreme temperature, etc. and the soil quality (Thalmann *et al*., 2017). Soil is also contaminated by heavy metals through various human activities (Moon *et al*., 2013), which affect plant growth and development and ultimately brings low yielding cropping systems. Mining is one of the important sources of heavy metal contamination in soil (Al-Farraj *et al*., 2013, Noman *et al*., 2017). The strength of soil is directly related to nutrient availability. Plants require a number of soil nutrients like nitrogen (N), phosphorus (P), and potassium (K) for their growth, but soil nutrient levels may decrease over time after crop harvesting, as nutrients are not returned to the soil. In India, the soil of many regions is not only deficient in macronutrients like NPK but also in secondary nutrients (e.g. sulfur, calcium, and magnesium) and micronutrients (e.g. boron, zinc, copper, and iron) (Pathak, 2010). Thus, to fulfill the shortage, a large amount of chemical fertilizers is added to the soil; however, only a small percent of water-soluble nutrients are taken up by the plants and the rest are converted into insoluble forms, making continuous application necessary. Finally, the extensive use of chemical fertilizers has led to the deterioration of the environment causing infinite problems. It not only lowers the nutrient composition of the crops but also degrades the soil fertility in the long run (Hariprasad *et al*., 2013, Yargholi *et al*., 2014).

Fungal diseases in *A. caudatus* have been observed to be caused by *Alternaria, Mycoplasma* and *Sclerotinia* spp. Pests causing economic damage to grain amaranths are mainly leaf-eating caterpillars (*Heliothis, Hymenia, Spodoptera*), stinkbugs (e.g. *Lygus* on the inflorescence), stem-boring larvae of weevils, grasshoppers and aphids (Agong, 2006). Tawfik *et al*., (1976) observed the stem-borer *Hypolixusnubilosus* attacking *A. caudatus* in Egypt, while *H. truncatulus* has been reported as a major pest of *A. caudatus* in the Jammu region in India (Tara *et a*l., 2009). *Pythiumaphanidermatum* was recorded as the causal agent of stem canker in *A. caudatus* for the first time in Argentina (Noelting and Sandoval, 2007). *Lewiainfectoria* (teleomorph of *Alternaria infectoria*) affecting panicles and seeds of *A. caudatus* subsp. *mantegazzianus* was also reported in Argentina for the first time (Noelting *et al*., 2012).

## 2.5 Effects of biochar and poultry manure on soil characteristics and the yield of different crops

The use of biochar (BC) and poultry manure (PM) had contrasted consequences on soil properties (Lima *et al*., 2021). Use of biochar (B) and poultry manure (PM) as soil amendments can improve the productivity and sustainability of tropical agriculture, the application of B and PM either alone or in combination improved soil physical and chemical properties, plant nutritional status, growth, and corm and cormel yields of cocoyam (Agbede *et al.,* 2020). According to Inal *et al*. (2015), PPM and biochar improved soil chemical properties of calcareous soil and increased maize and bean plant growth. Biochar and PPM decreased soil pH and increased plant nutrient (P, K, Mg, Cu, Zn and Mn) solubility and availability to plants but surprisingly decreased Fe availability. The largest application rate of biochar decreased exchangeable Ca concentrations in soil.

Application of B and PM alone, and in combination, improved soil physical and chemical properties, leaf nutrient concentrations and yield components of radish (Adekiya *et al*., 2019). Biochar, PM, NPK fertilizer alone or combinations of biochar and poultry manure and biochar and NPK fertilizer improved soil physical (reduced bulk density, and increased porosity and moisture content) and chemical (pH, OM, N, P, K, Ca and Mg) properties, growth and yield of ginger compared to the control (Adekiya *et al*., 2020). Biochar to manure plays a significant role in reducing leaching and promoting yield of Amaranthus (Agegnehu *et al*., 2015). It also suggests that addition of biochar will help when there is a rise in temperature due to climate change. Similar results were obtained for fresh and dry root weight at 30 and 37°C, but with poultry manure and with biochar recording the highest fresh root weight. Root development appear to be generally higher at higher temperature (37°C) than at lower temperature (30°C), and addition of biochar appears to promote growth and yield high temperature (Abubakari *et al.,* 2016).

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

### 3.1 Study areas

**Screenhouse**

The study was carried out in the screenhouse of Kwara State University, Malete (KWASU) Moro, Kwara State in the North Central Geopolitical zone of Nigeria in the year 2020. KWASU is located at Malete which lies on the altitude of 316.37m above sea level within latitude 08°43'N and longitude 4°28'E of the equator. The temperature varies between $33^{O}$C and $34^{O}$C, annual rainfall in the region is about 1200mm and during the period, with a dry spell from December to March. The Kwara State University land area forms part of the South-western region of Nigerian basement complex, a region of basement recurrence and plutonism during the Pan-African orogeny (Olowoake, 2017).

**Field Study**

The field study was carried out at the experimental field of the National Center for Agricultural Mechanization (NCAM), Idofian, Kwara State in the North Central Geopolitical zone of Nigeria in the year 2020. NCAM is located at Idofian which is about 20 km from Ilorin and lies on the altitude of 327m above sea level within latitude 08°23'N and longitude 4°43'E of the equator. It has mean annual rainfall of 1564 mm distributed. The temperature and relative humidity ranges between 29ºC in – 37ºC and 70% - 80%

during rainy season while that of dry season is between 38% and 50% respectively (Nigerian Meteorological Agency Lagos). The experimental site has been previously used to grow various crops ranging from legumes and cereals in the recent past and was left to fallow for a period of months before used for this study.

### 3.2 Collection of materials

The sawdust based biochar was collected from Institute of Agricultural Research and Training (IAR&T) Ibadan. NPK 20-10-10 was purchased from Ilorin. Poultry manure (PM) was obtained from the poultry unit of the Teaching and Research Farm of Kwara State University. *Amaranthus caudatus* seeds were obtained from a seed store in challenge, Ilorin, Kwara State. The chemical composition of Biochar and Poultry Manure used in the study is given in Table 1.

### 3.3 Chemical analysis of biochar and poultry manure materials

The biochar and poultry manure were analyzed for N, P and K. Total N was determined by the micro kjeldahl method.  P and K were determined by wet digestion method (Okalebo *et al*., 1993). The mixture of concentrated Nitric, Perchloric and sulphuric acid in a ratio of 25:5:5 respectively was used to digest 2 g of sample and then analyzed for P by vanadomolybdate method while K was measured with flame photometry (Okalebo *et al*., 1993).

## 3.4 Pre-planting soil sampling and analysis

Prior to land preparation, topsoil was randomly collected from different spots in the experimental site (National Centre for Agricultural Mechanization (NCAM), Ilorin) during the field layout and at a depth of 0-15 cm with auger, the 4 samples were bulked to form a composite sample from which a representative sample was air-dried and crushed. Soil samples were sieved through 2 mm. The soil particle size, pH, $H_2O$, Organic carbon, total N, available phosphorus (P), Potassium (K), Exchangeable Acidity, Magnesium (Mg), Calcium (Ca), Sodium (Na), Manganese (Mn), Copper (Cu), iron (Fe) and Zinc (Zn) were determined. Particle size was determined using hydrometer method. Soil pH was determined by pH meter using 1:2 soil water ratio. The soil organic carbon was determined using the Walkey –Black method and total N was determined from 0.5 mm of the soil using the macro kjeldahl procedure. Phosphorus was determined by Bray's P method. Exchangeable K, Ca and Mg were extracted with ammonium acetate extraction method. The K concentration in the extract was determined using the flame photometer; while Ca and Mg were determined by atomic absorption spectrophotometer (Okalebo *et al.*, 1993). Soil sample from KWASU Teaching and Research Farm used in the screenhouse also went through the same soil routine analysis as stated above.

**Table 1: Chemical composition of Biochar and Poultry Manure**

| | Nutrient (%) | | |
|---|---|---|---|
| | **Nitrogen (N)** | **Phosphorus (P)** | **Potassium (K)** |
| Biochar | 1.10 | 0.50 | 0.65 |
| Poultry manure | 2.50 | 0.21 | 3.41 |

## 3.5 SCREENHOUSE EXPERIMENT (Experiment 1)

### TITLE: Effect of biochar enriched with poultry manure on nutrient uptake and soil nutrient changes in Amaranthus

### 3.5.1 Treatments and experimental design

Soil sample from Teaching and Research Farm, Malete was used for the screenhouse experiment. The Twenty five kilogramme of soil samples already air-dried and passed through 2 mm sieve was weighed into 12 pots. Four treatments which consist of control, combination of 50 % poultry manure (PM) and 50 % biochar (BC) at 10, 20, and 30t/ha in three replicates. The experimental design is completely randomized design. Combination of poultry manure and biochar (PM +BC) was incorporated into the soil two weeks before sowing Amaranthus seeds. Five grams of seeds of Amaranthus was mixed with 500g sand and drilled in a 20-cm-diameter ring in each pot, and thinned to 2 seedlings after 2 weeks of germination. Watering and weeding were done throughout the experimental period. The plants were grown for six weeks after which they were harvested. At 6 weeks after planting(WAP), plants were ratooned by cutting at 5 cm above the soil line and plant regrowth was assessed at 2, 4 and 6th weeks after regeneration and harvested at 6weeks after regeneration. Plant and soil samples were taken and analyzed at the end of each growth cycle to determine the nutrient contents. The dried Amaranthus shoots were milled using Willey E. D. 5 milling equipment.

### Data collection

The following growth parameters were taken at an interval of two weeks; plant height, number of leaves, stem girth, fresh and dry weight. The parameters were taken in each growth cycle. Plant height was measured from the root collar to the growing tip. Plant stem girth was determined using vernier caliper. Numbers of fully expanded leaves were counted

### Plant analysis

2.0 g ground plant samples were taken into beaker and digested using wet digestion of a mixture of Nitric, Sulphuric and Perchloric acid. (Okalebo *et al*., 1993). Total Phosphorus was determined by Bray's method and total Nitrogen using the Kjeldahl procedure and Potassium determination by flame photometry (Okalebo *et al*., 1993). Nutrient uptake was determined by multiplying total dry matter yield (g) with nutrient content (%)

### Data analysis

The data collected were subjected to statistical analysis of variance and significant differences among the treatment means were evaluated using Least Significant Difference (LSD) at 5% probability.

## 3.6 FIELD EXPERIMENT

### 3.6.1 Experiment II

**TITLE: Effects of biochar supplemented with poultry manure on growth, yield of *Amaranthus* and soil properties.**

The experiment was set up under field condition(fig. 2) with the objective of assessing the most effective combination of biochar and poultry manure. The field was cleared, ploughed and harrow. The experimental design was laid out in a randomized complete block design (RCBD) with three replications. The size of each sub plot was 3.0 X 2.0 (6 m$^2$), with an inter-plot space of 1 m. The field trials had 5 major treatment combinations comprising

1. Control (No fertilizer)
2. PM (50%) +BC (50%) - 10 t/ha
3. PM (50%) +BC (50%) – 15 t/ha
4. PM (50%) +BC (50%) -20 t/ha
5. NPK 100 kg N/ha

Key: PM – Poultry manure BC- Biochar

Direct seed sowing was done at an inter-row and intra-row spacing of 50cm x 20cm and the seedlings were later thinned to one plant per stand. The combination of sawdust based biochar and poultry manure was incorporated to the soil 2 weeks before sowing of Amaranthus seeds. The experimental plots were weeded manually with hoe two (2) times to avoid weed from competing with the plant for nutrient.

**Data collection**

Five plants were tagged from the inner rows of each plot for growth and yield parameters. The following growth parameters were taken at an interval of two weeks; plant height, stem girth, number of leaves per plant, fresh and dry weight yield.

### Chemical analysis of plant and soil samples

Plant tissue was sampled for determination of nutrient concentration. Amaranthus leaves were sampled per plot at 6 weeks after planting. The sampled leaves were oven-dried at 70 $^0$C to a constant weight. The dried samples were then ground to pass through a 2 mm sieve. Milled and sieved samples were subjected to digestion using wet method of a mixture of Nitric sulphuric and perchloric acid (Okalebo *et al*., 1993). Nitrogen, Phosphorus and Potassium were determined as described in experiment 1. Nutrient uptake was determined by multiplying total dry matter yield (g) with nutrient content (%). Also, soil sampling (0-15 cm soil depth) was carried out on each plot at harvesting stage. The sampled soil was air dried and passed through a 2 mm sieve for analysis of C, N, P, K, Soil pH and mechanical analysis of the soil in the laboratory using the procedure described by Okalebo *et al*., (1993).

**Statistical analysis:** Data collected were subjected to Statistical Analysis System (SAS) for Analysis of variance (ANOVA) and the treatments were compared at 5 % level of significance using the Duncan's Multiple Range Test (DMRT).

| Block 1 | Block 2 | Block 3 |
|---|---|---|
| CONTROL | PM (50%) +BC (50%)-<br>20 t/ha | NPK-100 kgN/ha |
| PM (50%) +BC (50%)-<br>15 t/ha | PM (50%) +BC (50%)-<br>15 t/ha | PM (50%) +BC (50%)-<br>20 t/ha |
| PM (50%) +BC (50%)-<br>20 t/ha | CONTROL | PM (50%) +BC (50%)-<br>10 t/ha |
| PM (50%) +BC (50%)-<br>25 t/ha | NPK-100 kgN/ha | PM (50%) +BC (50%)-<br>15 t/ha |
| NPK-100 kgN/ha | PM (50%) +BC (50%)-<br>10 t/ha | CONTROL |

**Figure 2:** Experimental plot layout

### 3.6.2 EXPERIMENT III

**TITLE**: **To evaluate the residual effect of soil amendment with biochar supplemented with poultry manure on the growth, yield of *Amaranthus* and soil properties.**

There was no further application of fertilizer treatments than the one applied in previous experiment(II). The planting was done immediately after the termination of the first experiment. Plots were manually cleared and planting was done. Weeding was also carried out manually.

### Data collection

The following growth parameters were taken at an interval of two weeks; plant height, stem girth, number of leaves per plant, fresh and dry weight yield.

### Physico-chemical analyses

Plant tissue and soil analyses were carried out for the determination of plant nutrients and the residual effects of the treatments on the experimental soil as explained in experiment II.

### Statistical analysis

The data collected were subjected to Statistical Analysis System (SAS) for analysis of variance (ANOVA) using Duncan’s Multiple Range Test (DMRT) at 5 % probability level.

# CHAPTER FOUR

## 4.0 RESULTS

## 4.1 Physico-chemical properties of experimental soil

The physical and chemical properties of the soil for screenhouse and field studies are presented in Table 2. The Teaching and Research Farm soil had the pH of ($H_2O$) 6.7 which could be described as neutral. The organic carbon, total N and available P values were 0.72, 0.08 (g/kg) and 5 mg/kg respectively. Textural class of the soil is sandy loam. The exchangeable K, Mg, Ca, Na, Exch. Acidity and Mn were 0.4 mg/kg, 1.3 cmol/kg, 5 mg/kg, 0.8 cmol/kg, 0.30 cmol/kg and 121 mg/kg respectively. The field experimental soil had a pH ($H_2O$) of 6.9 which could be described as neutral. The textural class of the soil are loamy sand. The organic carbon, total N and available P values were 1.21, 0.14 (g/kg) and 7 mg/kg respectively. The exchangeable K, Mg, Ca, Na, Exch. Acidity(cmol/kg) and Mn are 0.24, 1.38, 1.98, 0.70, 0.30 and 110 mg/kg respectively.

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**Table 2: Physico-chemical properties of experimental soil**

| **Parameters** | **-------- Soil test value—----** | |
|---|---|---|
| | **NCAM (Field)** | **Teaching and research farm (Screenhouse)** |
| pH | 6.90 | 6.7 |
| Org. C (%) | 1.21 | 0.72 |
| Total N (%) | 0.14 | 0.08 |
| P ($mgkg^{-1}$) | 6 | 5 |
| **Exchangeable bases (c mol $kg^{-1}$)** | | |
| K | 0.2 | 0.4 |
| Mg | 1.4 | 1.3 |
| Ca | 2.0 | 5.5 |
| Na | 0.7 | 0.8 |
| Exch. Acidity | 0.3 | 0.3 |
| **Extractablemicro-nutrients** ($mgkg^{-1}$) | | |
| Fe | 98 | 120 |
| Zn | 0.9 | 0.9 |
| Cu | 1.0 | 1.1 |
| Mn | 110 | 121 |
| **Mechanical composition (gkg)** | | |
| Sand | 790 | 770 |
| Silt | 130 | 150 |
| Clay | 80 | 80 |
| Textural class | Loamy Sand | Sandy Loam |

## 4.2 Effect of biochar supplemented with poultry manure on the growth and yield parameters of Amaranthus during the first cycle in the screenhouse

### Plant height

Table 3 shows the response of plant height of Amaranthus to application of biochar supplemented with poultry manure during the first cycle of growth in the screenhouse. At 2weeks after planting (WAP), there was no significant ($p < 0.05$) differences among the treatments on Amaranthus treated with different rates of Biochar and Poultry manure. At 4 weeks after planting (WAP), PM (50%) + BC (50%) at 30 t/ha had the highest plant height followed by PM (50%) + BC (50%) at 20 t/ha and were significantly ($p< 0.05$) different from PM(50%)+BC(50%) at 10 t/ha and control. However, at 6 WAP, PM (50%) + BC (50%) at 20 t/ha had the highest plant height followed by PM (50%) + BC (50%) at 30 t/ha and were significantly ($p< 0.05$) different from PM (50%) + BC (50%) at 10 t/ha and control.

### Number of Leaves

Table 4 shows the response of number of leaves of Amaranthus to application of Biochar supplemented with Poultry manure during the first cycle of growth in the screenhouse. At 2 WAP, the number of leaves in PM (50%) + BC (50%) at 20 t/ha and PM (50%) + BC (50%) at 30 t/ha were significantly ($p< 0.05$) different from number of leaves produced from PM(50%)+BC(50%) at 10 t/ha and control. At 4 WAP, there was no significance (p

$< 0.05$) differences among the number of leaves treated with different rates of PM (50%) + BC (50%) and control. However, at 6 WAP, the number of leaves treated with PM (50%) + BC (50%) at 20 t/ha and PM (50%) + BC (50%) at 30 t/ha were significantly higher than number of leaves from PM (50%) + BC (50%) at 10 t/ha and control.

**Table 3: Plant height of Amaranthus as influenced by application of Biochar supplemented with Poultry manure during the first cycle of growth in the screenhouse**

| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | ______ cm ______ | | |
| | 2 | 4 | 6 |
| Control | 1.9a | 3.0c | 5.2d |
| PM(50%) +BC(50%) at 10t/ha | 2.1a | 5.9b | 10.7c |
| PM(50%) +BC(50%) at 20t/ha | 3.8a | 12.3a | 23.1a |
| PM(50%) +BC(50%) at 30t/ha | 3.8a | 12.8a | 20.6b |

Means having the same letter along the columns indicate no significant difference using Least Significant Difference (LSD) at 5% probability level

Legend:

PM -poultry manure

BC –biochar

**Table 4: Number of Leaves of Amaranthus as influenced by application of Biochar supplemented with Poultry manure during the first cycle of growth in the screenhouse**

| Treatment | Weeks After Planting (WAP) |
|---|---|

|  | 2 | 4 | 6 |
|---|---|---|---|
| Control | 3.0c | 6.0b | 7.0c |
| PM(50%) +BC(50%) at 10t/ha | 3.7bc | 6.3b | 9.3b |
| PM(50%) +BC(50%) at 20t/ha | 5.7a | 9.0a | 12.0a |
| PM(50%) +BC(50%) at 30t/ha | 5.3b | 9.7a | 11.7a |

Means having the same letter along the columns indicate no significant difference using Least Significant Difference (LSD) at 5% probability level

Legend:

PM -poultry manure

BC -biochar

**Stem Girth**

Table 5 shows the response of stem girth of Amaranthus to application Biochar supplemented with Poultry manure during the first growing period in the screen house. At 2 WAP, there were no significance ($p < 0.05$) differences among the stem girth of Amaranthus treated with fertilizers and control. At 4 WAP the stem girth of Amaranthus treated with PM (50%) + BC (50%) at 10,20, and 30 t/ha were significantly ($p< 0.05$) different from stem girth obtained from control pot. However, at 6WAP, Amaranthu*s* stem girth with values of 6.30 mm produced from PM (50%) + BC (50%) at 20 t/ha was significantly ($p< 0.05$) better than all stem girth produced from other treatments including control.

**Fresh Shoot Weight and Dry matter yield**

Table 6 shows the response of fresh weight and dry matter yield of Amaranthus to application biochar supplemented with poultry manure during the first cycle of growth in the screenhouse. Fresh shoot weight produced from PM (50%) + BC (50%) at 20 and 30t/ha were significantly ($p< 0.05$) different from PM (50%) + BC (50%) at 10 t/ha and control. The results also shows that dry matter yield produced from PM (50%) + BC (50%) at 20 and 30 t/ha were significantly ($p< 0.05$) different from PM (50%) + BC (50%) at 10 t/ha including control.

**Table 5: Stem Girth of Amaranthus as influenced by application of Biochar supplemented with Poultry manure during the first cycle of growth in the screenhouse**

| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | mm | | |
| | 2 | 4 | 6 |
| Control | 0.17a | 0.73b | 2.07b |
| PM(50%)+BC(50%) at 10t/ha | 0.17a | 1.60ab | 3.37ab |
| PM(50%)+BC(50%) at 20t/ha | 0.37a | 3.40a | 6.30a |
| PM(50%)+BC(50%) at 30t/ha | 0.30a | 3.43a | 4.73ab |

Means having the same letter along the columns indicate no significant difference using Least

Significant Difference (LSD) at 5% probability level

Legend:

PM -poultry manure

BC-biochar

**Table 6: Fresh Shoot weight and dry matter yield of Amaranthus as influenced by application of Biochar supplemented with Poultry manure during the first cycle of growth in the screenhouse**

| Treatment | g/pot | |
|---|---|---|
| | Fresh shoot Weight | DryMatter yield |
| Control | 0.67b | 0.03c |
| PM(50%)+BC(50%) at 10t/ha | 2.07b | 0.40bc |
| PM(50%)+BC(50%) at 20t/ha | 9.27a | 1.60a |
| PM(50%)+BC(50%) at 30t/ha | 6.90ab | 1.50ab |

Means having the same letter along the columns indicate no significant difference using Least Significant Difference (LSD) at 5% probability level

Legend:

PM -poultry manure

BC -biochar

## Nutrient Uptake

Table 7 shows the nutrient uptake of Amaranthus to application Biochar supplemented with Poultry manure during the first cycle of growth in the screenhouse. Nutrient uptake of N, P, and K in Amaranthus plants differed significantly ($p<0.05$) among the different fertilizer treatments during the first cycle of growth. For the N uptake, the highest value of 0.73 mg N / pot was observed in plants treated with PM (50%) + BC (50%) at 20 t/ha and was significantly ($p <0.05$) higher than the values of other treatments including control. P uptake values show that PM (50%) + BC (50%) at 20 t/ha had highest value (0.77mg P / pot). K uptake had the values of 36.98mg K/pot from the treatment PM (50%) + BC (50%) at 20 t/ha. In general, control had the lowest nutrient uptake among the treatments followed by application of PM (50%) + BC (50%) at 10t/ha.

**Table 7: Nutrient Uptake of Amaranthus as influenced by application of Biochar supplemented with Poultry manure during the first cycle of growth in the screen house**

| Treatment | Nutrient Uptake | | |
|---|---|---|---|
| | mg/pot | | |
| | N | P | K |
| Control | 0.05c | 0.02c | 0.06d |
| PM(50%)+BC(50%) at 10t/ha | 0.21c | 0.19b | 2.05c |
| PM(50%)+BC(50%) at 20t/ha | 0.73a | 0.77a | 36.98a |
| PM(50%)+BC(50%) at 30t/ha | 0.59b | 0.76a | 6.94b |

Means having the same letter along the columns indicate no significant difference using Least Significant Difference at 5% probability level

Legend:

PM -poultry manure

BC -biochar

## 4.3 Residual effects of biochar supplemented with poultry manure on some soil chemical and physical properties of post plant soil in the screenhouse

The effect of application of biochar supplemented with poultry manure treatments at different rates on the experimental soil at harvesting are presented in Tables 8. At first harvest stage of Amaranthus, pH value ranged from 6.41 in control pot to 6.93 in PM (50%) + BC (50%) at 30 t/ha. Application of PM (50%) + BC (50%) at 30 t/ha increased soil pH value than other treatment including control. Soil available P content ranged from 6.00 mg kg-1 in control pot to 27.48 mg/ kg in PM (50%) + BC (50%) at 30 t/ha. Soil treated with PM (50%) + BC (50%) at 20 and 30 t/ha increased soil exchangeable K content in the soil over PM (50%) + BC (50%) at 10 t/ha and control pot. This value was 17.4 and 4.3 % higher than control and PM (50%) + BC (50%) at 10 t/ha respectively. Soil organic carbon ranged from 0.41% in control pot to 0.54% in pot that received 30 t /haPM (50%) + BC (50%). Total N varied between 0.05% in control pot and 0.06% in 10 and 20 t/ha PM (50%) + BC (50%) respectively. These values indicate a general increase in N, P and K in soil treated with biochar and poultry manure compared with control.

**Pearson correlation coefficients between dry matter and nutrient uptake after first harvest in the screenhouse.**

Table 9 shows the correlation coefficient analysis for dry matter and N, P and K uptake after first harvest in the screenhouse. Pearson correlation coefficients between Amaranthus dry matter yield and N P K uptake were positively correlated after first harvest. At first harvest, positive relationships exist between dry matter yield and N ($R^2$= 0.9775); P ($R^2$= 0. 9983) and K uptake ($R^2$= 0.6826).

**Table 8: Residual effects of biochar supplemented with poultry manure on some soil chemical and physical properties at harvest during first cycle of planting in the screenhouse**

| Treatment | pH ($H_20$) | Available P | OC | N | K |
|---|---|---|---|---|---|
| | | mg $kg^{-1}$ | % | | cmol $kg^{-1}$ |
| Control | 6.41d | 6d | 0.41c | 0.05b | 0.2c |
| PM(50%)+BC(50%) at 10t/ha | 6.54c | 15c | 0.41c | 0.06a | 0.2a |
| PM(50%)+BC(50%) at 20t/ha | 6.90b | 23b | 0.43b | 0.06a | 0.2b |
| PM(50%)+BC(50%) at 30t/ha | 6.93a | 27.a | 0.54a | 0.05b | 0.2a |

Means having the same letter along the columns indicate no significant difference using Least Significant Difference at 5% probability level.

Legend:

PM -poultry manure

BC -biochar

**Table 9: Pearson correlation coefficients between dry matter and nutrient uptake after first harvest in the screen house.**

| Parameters | Dry Matter | N | P | K |
|---|---|---|---|---|
| DryMatter | 1.0000 | | | |
| N | 0.9775** | 1.0000 | | |
| P | 0.9983** | 0.9865** | 1.0000 | |
| K | 0.6826** | 0.7909** | 0.7185** | 1.0000 |

*Significant at the 0.05 level. ** Significant at the 0.01 level.

## 4.4 Effect of Biochar supplemented with Poultry manure on the growth and yield parameters of Amaranthus during the re-growth in the screenhouse

### Plant height

Table 10 shows the response of plant height of Amaranthus to application of biochar supplemented with poultry manure during the re-growth in the screen house. At 2weeks after planting (WAP), there were no significant ($p < 0.05$) differences among the plant height of Amaranthus treated with different rates of biochar supplemented with poultry manure. At 4 weeks after planting (WAP), PM (50%) + BC (50%) at 30 t/ha had the highest plant height followed by PM (50%) + BC (50%) at 20 t/ha and were significantly ($p< 0.05$) different from PM (50%) + BC (50%) at 10 t/ha and control. However, at 6 weeks after planting (WAP), there were no significance ($p < 0.05$) differences among the plant height of Amaranthus treated with different rates of biochar supplemented with poultry manure except control that differ significantly from other fertilizer treatments. However, PM (50%) + BC (50%) at 30 t/ha had the highest plant height.

### Number of Leaves

Table 11 shows the response of number of leaves of Amaranthus to application biochar supplemented with poultry manure during the re-growth in the screenhouse. At 2 WAP, the number of leaves in PM (50%) + BC (50%) at 20 t/ha and PM (50%) + BC (50%) at 30 t/ha were significantly ($p< 0.05$) higher than number of leaves from PM (50%) + BC

(50%) at 10 t/ha and control. At 4 WAP, the number of leaves in PM (50%) + BC (50%) at 20 t/ha produced the highest number of leaves (28.7) and was significantly ($p < 0.05$) higher than number of leaves from all other fertilizer treatments including control. At 6 WAP, the number of leaves produced from PM (50%) + BC (50%) at 10 and 20 t/ha were significantly ($p < 0.05$) higher than number of leaves from PM (50%) + BC (50%) at 30 t/ha and control. However, there was no significance difference between PM (50%) + BC (50%) at 10 t/ha and PM (50%) + BC (50%) at 20 t/ha.

**Table 10: Plant height of Amaranthus as influenced by application of biochar supplemented with poultry manure during the re-growth in the screenhouse**

| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | cm | | |
| | 2 | 4 | 6 |
| Control | 2.7b | 4.0c | 7.8b |
| PM(50%) +BC(50%) at 10t/ha | 5.3a | 13.1b | 24.1a |
| PM(50%) +BC(50%) at 20t/ha | 5.9a | 20.6ab | 35.8a |
| PM(50%) +BC(50%) at 30t/ha | 7.2a | 23.2a | 36.2a |

Means having the same letter along the columns indicate no significant difference using Least Significant Difference at 5% probability level

Legend:

PM -poultry manure

BC -biochar

**Table 11: Number of leaves of Amaranthus as influenced by application of biochar supplemented with poultry manure during the re-growth in the screenhouse**

| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | 2 | 4 | 6 |
| Control | 3.3d | 8.0d | 11.0c |
| PM(50%)+BC(50%) at 10t/ha | 8.3c | 24.7b | 29.7a |
| PM(50%)+BC(50%) at 20t/ha | 14.0a | 28.7a | 28.7a |
| PM(50%)+BC(50%) at 30t/ha | 11.3b | 22.0c | 25.0b |

Means having the same letter along the columns indicate no significant difference using Least Significant Difference at 5% probability level

Legend:

PM -poultry manure

BC -biochar

### Stem Girth

Table 12 shows the response of stem girth of Amaranthus to application of biochar supplemented with poultry manure during the re-growth in the screenhouse. At 2 WAP, 4 WAP and 6 WAP there were no significant difference between the stem girth produced from PM (50%) + BC (50%) at 20 t/ha and PM (50%) + BC (50%) at 30 t/ha. However, the duo were significantly ($p < 0.05$) higher than other stem girth produced from PM (50%) + BC (50%) at 10 t/ha and control throughout the growing period.

### Fresh shoot weight and Dry matter yield

Table 13 shows the response of fresh shoot weight and dry matter yield of Amaranthus to application biochar supplemented with poultry manure during the re-growth in the screen house. Fresh shoot weight produced from PM (50%) + BC (50%) at 20 t/ha and PM (50%) + BC (50%) at 30 t/ha were significantly ($p < 0.05$) different from PM (50%) + BC (50%) at 10 t/ha and control. Also, dry matter yield from PM (50%) + BC (50%) at 20 t/ha and PM (50%) + BC (50%) at 30 t/ha were significantly ($p < 0.05$) higher than yield produced from PM (50%) + BC (50%) at 10 t/ha and control.

**Table 12: Stem Girth of Amaranthus as influenced by application of Biochar supplemented with Poultry manure during the re-growth in the screenhouse**

| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | mm | | |
| | 2 | 4 | 6 |
| Control | 2.27c | 1.60c | 2.70c |
| PM(50%)+BC(50%) at 10t/ha | 3.47b | 4.63b | 5.63b |
| PM(50%)+BC(50%) at 20t/ha | 6.83a | 7.67a | 9.13a |
| PM(50%)+BC(50%) at 30t/ha | 5.70a | 6.60a | 7.67a |

Means having the same letter along the columns indicate no significant difference using Least Significant Difference at 5% probability level

Legend:

PM -poultry manure

BC -biochar

**Table 13: Fresh Weight and Dry matter of Amaranthus as influenced by application of biochar supplemented with poultry manure during the re-growth in the screen house**

| Treatment | g<br>Fresh shoot Weight(g) | <br>DryMatter yield(g) |
|---|---|---|
| Control | 1.50d | 0.43c |
| PM(50%)+BC(50%) at 10t/ha | 12.37c | 2.57b |
| PM(50%)+BC(50%) at 20t/ha | 27.9a | 7.57a |
| PM(50%)+BC(50%) at 30t/ha | 21.9b | 5.87a |

Means having the same letter along the columns indicate no significant difference using Least Significant Difference at 5% probability level

Legend:

PM -poultry manure

BC -biochar

## Nutrient Uptake

Nutrient uptake of N, P, and K in Amaranthus plants differed significantly ($P<0.05$) among the different fertilizer treatments during the re-growth in the screenhouse (Table 14). For the N uptake, the highest value of 2.57 mg N/pot was observed in plants treated with PM (50%) + BC (50%) at 20 t/ha and was significantly ($P<0.05$) higher than the values of other treatments including control. P uptake values show that PM (50%) + BC (50%) at 20 t/ha had highest value (2.92 mg P / pot). K uptake had the values of124.37mg K /pot from the treatment PM (50%) + BC (50%) at 20 t/ha. However, PM (50%) + BC (50%) at10 t/ha had the lowest value of 10.52 mg K / pot among the fertilizer treatment applications.

**Table 14: Nutrient Uptake of Amaranthus as influenced by application of Biochar supplemented with Poultry manure during the re-growth in the screen house**

| Treatment | Nutrient Uptake | | |
|---|---|---|---|
| | mg/pot | | |
| | N | P | K |
| Control | 0.06c | 0.04c | 2.17c |
| PM(50%)+BC(50%) at 10t/ha | 0.80c | 0.87b | 10.52bc |
| PM(50%)+BC(50%) at 20t/ha | 2.57a | 2.92a | 124.37a |
| PM(50%)+BC(50%) at 30t/ha | 1.78b | 2.45a | 39.73b |

Means having the same letter along the columns indicate no significant difference using Least Significant Difference at 5% probability level

Legend:

PM -poultry manure

BC -biochar

**Physico-chemical analysis of the soil after the harvesting**

The effects of application of different rates of biochar supplemented with poultry manure on the experimental soil after harvesting are presented in Tables 15. At harvesting stage of Amaranthus, pH value ranged from 7.03 in control pot to 7.31 in PM (50%) + BC (50%) at 20t/ha. Application of PM (50%) + BC (50%) at 20t/ha increased soil pH value than other treatment including control. Soil available P content in soil ranged from 6.24 mg kg$^{-1}$ in control pot to 27.40mg kg$^{-1}$ in PM (50%) + BC (50%) at 20t/ha, which was higher than the pot treated with different rate of poultry manure supplemented with biochar. Soil organic carbon ranged from 0.18%in control pot to 0.90% in pot with PM (50%) + BC (50%) at 20t/ha. Total N varied between 0.02% in control pot to 0.10% in PM (50%) + BC (50%) at 20t/ha. The soil in control pot had available K content of 0.20 mgkg$^{-1}$, which is similar to pot treated with PM (50%) + BC (50%) at 10 t/ha while PM (50%) + BC (50%) at 20t/ha had available K content of 0.21 mgkg$^{-1}$.

## Pearson correlation coefficients between dry matter and nutrient uptake after second harvest (re-growth) in the screen house.

Pearson correlation coefficients between dry matter and N P K uptake were positively correlated and after re-growth of Amaranth in the screenhouse (Table 16). Positive relationships exist between dry matter yield and N ($R^2$= 0.9963); P ($R^2$= 0.9956) and K uptake ($R^2$= 0.6345).

**Table 15: Physico-chemical analysis of the soil after the re-growth**

Means having the same letter along the columns indicate no significant difference using

| Treatment | pH ($H_20$) | Available P | OC | N | K |
|---|---|---|---|---|---|
| | | mg kg$^{-1}$ | % | | cmol kg$^{-1}$ |
| Control | 7.03d | 6d | 0.18c | 0.02c | 0.2b |
| PM(50%)+BC(50%) at 10t/ha | 7.11c | 11c | 0.27b | 0.03b | 0.2b |
| PM(50%)+BC(50%) at 20t/ha | 7.31a | 27a | 0.90a | 0.10a | 0.2a |
| PM(50%)+BC(50%) at 30t/ha | 7.15b | 20b | 0.27b | 0.03b | 0.2b |

Least Significant

Difference at 5% probability level.

Legend:

PM -poultry manure

BC -biochar

**Table 16: Pearson correlation coefficients between dry matter and nutrient uptake after second harvest(re-growth) in the screen house.**

| Parameters | Dry Matter | N | P | K |
|---|---|---|---|---|
| DryMatter | 1.0000 | | | |
| N | 0.9963** | 1.0000 | | |
| P | 0.9956** | 0.9884** | 1.0000 | |
| K | 0.6345** | 0.5740* | 0.6909** | 1.0000 |

*Significant at the 0.05 level. ** Significant at the 0.01 level.

### Analysis of variance of Amaranthus growth cycle, biochar supplemented with poultry manure rates and interactions

Amaranthus growth was affected by biochar supplemented with poultry manure rates, growth cycle, and their interaction (Table 17). Plant height at 6 weeks was affected by biochar supplemented with poultry manure rates and cropping cycle. Application of different rates of biochar supplemented with poultry manure resulted in comparable plant heights; the tallest plants were with treatment 20 t/ha at initial growth (23.1 cm), but 32.6 cm was produced by 30 t/ha in regenerated plants (Fig 3A). Stem girth was influenced by biochar supplemented with poultry manure rates and cropping cycle, but no interaction between the duo (Table 17). Stem girth increased with biochar supplemented with poultry manure at 20 t/ha during regrowth period (Figure 3B). Initial growth plants generally had thinner stems (Figure 3B).

Number of leaves/plants was affected by biochar supplemented with poultry manure rates and cropping cycle, but no interaction between them (Table 17). Biochar supplemented with poultry manure application at 20 t/ha produced numbers of leaves/plant, which were higher than 0 and 10 t/ha (Figure 3C). Plants from regrowth had more leaves than from initial growth (Figure 3C).

Enriched biochar rate, cropping cycle, and their interaction affected fresh yield (Table 17). Fresh shoot weight was highest with 20 t/ha. Application of 10 t/ha resulted in lower fresh yields (Figure 3D). Initial yields was lower than regrowth yield (Figures 3D).

**Table 17: Mean square from combined analysis for the Amaranthus growth and yield parameters during first and second cropping cycle in the screenhouse**

| Source of variation | Df | Plant height | Number of leaves | Stem girth | Fresh weight | Dry matter yield |
|---|---|---|---|---|---|---|
| Cropping cycle (C) | 1 | 740.37** | 1107.04** | 28.17** | 752.08** | 62.40** |
| Biochar amended rate (R) | 3 | 695.82** | 165.93* | 31.51** | 359.75** | 23.65** |
| C x R | 3 | 50.15 NS | 73.49 NS | 1.69 NS | 88.99* | 9.13** |

NS, *, **:Non-significant or significant at P = 0.05 and 0.01 respectively.

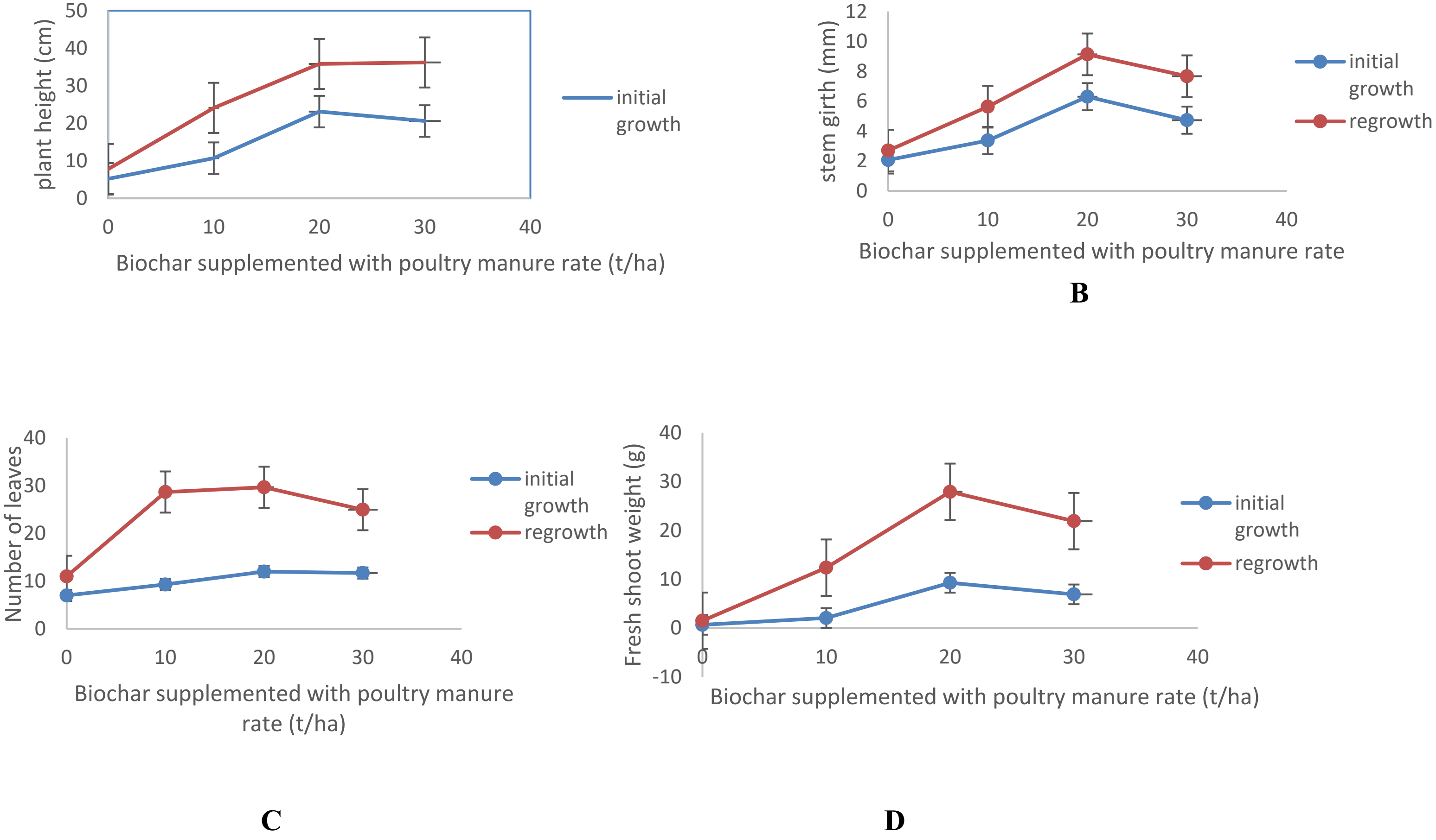


**Fig. 3. Growth of Amaranthus at 6 weeks after planting with biochar supplemented with poultry manure rates and cycle of growth**

## 4.5 Effect of Biochar supplemented with Poultry manure on the growth and yield parameters of Amaranthus during the first planting on the field

### Plant height

Table 18 shows the response of plant height of Amaranthus to application of biochar supplemented with poultry manure and NPK during the first growing period on the field. There was a general increase in the mean plant height throughout the growing period and there were significant difference among all the treatments. At 2 weeks after planting (WAP), PM (50%) + BC (50%) at 15 t/ha had the highest plant height followed by PM (50%) + BC (50%) at 10 t/ha and were significantly ($p < 0.05$) different from NPK and control. However, Amaranthus plant height potted with PM (50%) + BC (50%) at 10, 15 and 20 t/ha were not significantly different from each other. At 4 WAP, PM (50%) + BC (50%) at 15 t/ha had the highest plant height of 45.7cm and was significantly ($p < 0.05$) different from all other treatments including NPK and control. However, at 6 weeks after planting (WAP), the plant height of Amaranthus that received PM (50%) + BC (50%) at 15 t/ha showed the highest means of 65.3cm, followed by PM (50%) + BC (50%) at 20 t/ha (48.6cm) and PM (50%) + BC (50%) at 10 t/ha (47.2cm) and these were significantly ($p < 0.05$) different from NPK and control.

### Number of Leaves

Table 19 shows the response of number of leaves of Amaranthus to application of biochar supplemented with poultry manure and NPK during the first growing period on the field. At 2 weeks after planting (WAP), there were no significant difference between the numbers of leaves of Amaranthus grown among the PM (50%) + BC (50%) at 10, 15, 20 t/ha respectively. At 4 WAP, the number of leaves in PM (50%) + BC (50%) at 15 t/ha was significantly ($p< 0.05$) higher than number of leaves from other treatments including NPK and control. However, there were no significant difference in number of leaves produced from PM (50%) + BC (50%) at 10, 20 t/ha and NPK at 100 kgN/ha. At 6 WAP the number of leaves produced from PM (50%) + BC (50%) at 15 t/ha gave the highest number of leaves (58.7) and was significantly ($p< 0.05$) higher than number of leaves from all other treatments including NPK and control.

**Table 18: Plant Height of Amaranthus as influenced by application of biochar supplemented with poultry manure during the first planting on the field**

| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | cm | | |
| | 2 | 4 | 6 |
| Control | 4.3bc | 18.9d | 36.2c |
| PM(50%)+BC(50%) at 10t/ha | 5.9ab | 32.8bc | 47.2b |
| PM(50%)+BC(50%) at 15t/ha | 6.4a | 45.7a | 65.3a |
| PM(50%)+BC(50%) at 20t/ha | 5.4ab | 36.7b | 48.6b |
| NPK (100 kg N/ha) | 3.3c | 27.3c | 39.3c |

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level.

Legend:

PM -poultry manure

BC –biochar

**Table 19: Number of Leaves of Amaranthus as influenced by application of biochar supplemented with poultry manure during the first planting on the Field**

| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | 2 | 4 | 6 |
| Control | 5.0b | 25.0c | 32.3d |
| PM(50%)+BC(50%) at 10t/ha | 5.3a | 37.7b | 43.7c |
| PM(50%)+BC(50%) at 15t/ha | 5.7a | 49.0a | 58.7a |
| PM(50%)+BC(50%) at 20t/ha | 5.3a | 36.7b | 47.0b |
| NPK (100 kg N/ha) | 4.0b | 32.7b | 39.7c |

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level.

Legend:

PM -poultry manure

BC -biochar

### Stem Girth

Table 20 shows the response of stem girth of Amaranthus to application of biochar supplemented with poultry manure and NPK during the first growing period on the field. At 2 WAP, there was no significance ($p<0.05$) differences among the stem girth of Amaranthus treated with PM (50%) + BC (50%) at 10 and 15 t/ha, but the duo were significant different from all other treatments including control. At 4 WAP, the stem girth of Amaranthus treated with PM (50%) + BC (50%) at 15 t/ha was significantly ($p< 0.05$) higher than all other stem girth produced from PM (50%) + BC (50%) at 10, 20 t/ha and NPK including the control. However, at 6WAP, Amaranthu*s* stem girth with values of 5.17 mm produced from treatment PM (50%) + BC (50%) at 15 t/ha was significantly ($p< 0.05$) higher than all other stem girth produced from PM (50%) + BC (50%) at 10, 20 t/ha, NPK and control. Throughout the growing period, PM (50%) + BC (50%) at 15 t/ha produced the highest stem girth while control consistently had the smallest stem girth.

### Amaranthus Yield

Figure 4 shows the response of yield of Amaranthus to application of biochar supplemented with poultry manure and NPK during the first growing period on the field. Treatment PM (50%) + BC (50%) at 15 t/ha had the highest yield of 8.60 t/ha, followed by PM (50%) + BC (50%) at 10 t/ha (7.30 t/ha) followed by PM (50%) + BC (50%) at 20 t/ha (3.60 t/ha) and NPK (3.60 t/ha) then control (2.0 t/ha). Therefore PM (50%) + BC (50%) at 15 t/ha was significantly ($p< 0.05$) different from all other treatment including NPK and control.

**Table 20: Stem Girth of Amaranthus as influenced by application of biochar supplemented with poultry manure during the first planting on the Field**

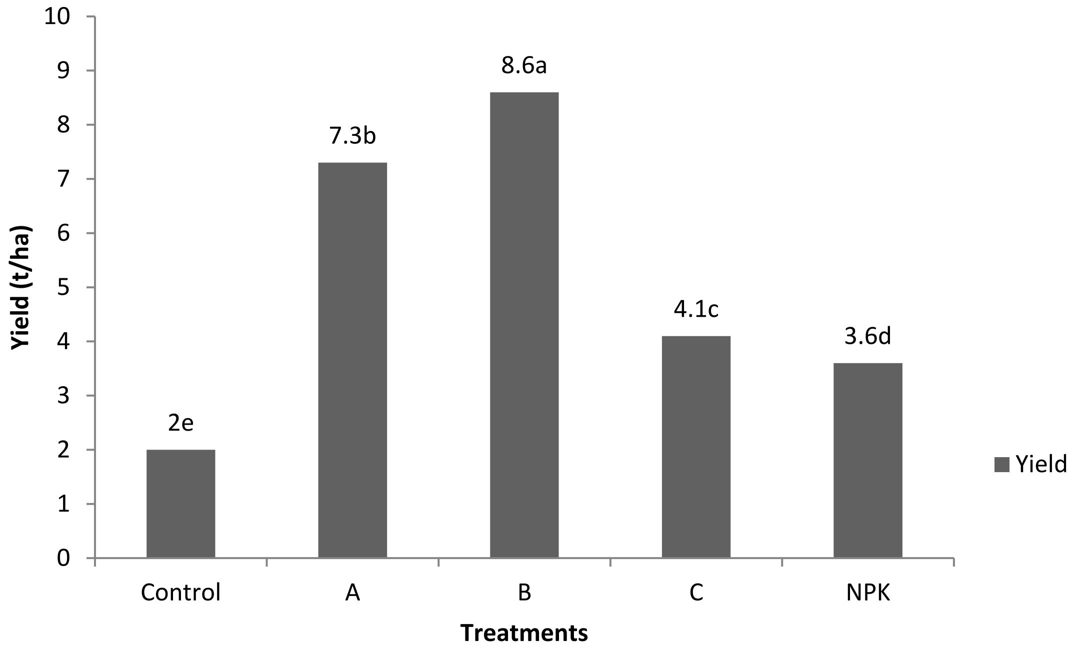
| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | mm | | |
| | 2 | 4 | 6 |
| Control | 1.10c | 1.87c | 2.63c |
| PM(50%)+BC(50%) at 10t/ha | 2.13a | 3.80b | 4.33b |
| PM(50%)+BC(50%) at 15t/ha | 2.10a | 4.80a | 5.17a |
| PM(50%)+BC(50%) at 20t/ha | 1.87b | 3.53b | 4.00b |
| NPK (100 kg N/ha) | 1.60b | 3.20b | 3.33b |

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level.

Legend:

PM -poultry manure

BC -biochar



Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level

**Figure 4. Effect of biochar supplemented with poultry manure and NPK on yield of Amaranthus during first planting**

Legend:

A - PM(50%)+BC(50%) at 10 t/ha B- PM(50%)+BC(50%) at 15 t/ha

C- PM(50%)+BC(50%) at 20 t/ha PM -poultry manure

BC –biochar

**Residual physico-chemical analysis of the soil at harvest during first cropping on the field**

The effects of application of different rates of biochar supplemented with poultry manure and NPK on the experimental soil at harvest during first cropping are presented in Tables 21. At harvesting stage of Amaranthus, soil pH value ranged from 6.38 in control plot to 7.75 in plot of PM (50%) + BC (50%) at 15 t/ha. Application of PM (50%) + BC (50%) at 15 t/ha resulted into higher than other treatment including control. Soil available P content in soil ranged from 11.6 mg $kg^{-1}$ in control plot to 56.8 mg $kg^{-1}$ in PM (50%) + BC (50%) at 15 and 20 t/ha, which was higher than the plot treated with PM (50%) + BC (50%) at 10 t/ha and NPK. Soil organic carbon ranged from 0.27 g $kg^{-1}$ in control plot to 1.35 g $kg^{-1}$ in plot with PM (50%) + BC (50%) at 20 t/ha. Total N varied between 0.03 g $kg^{-1}$ in control and 0.15 g $kg^{-1}$ in PM (50%) + BC (50%) at 20 t/ha plot. The soil in control plot had exchangeable Ca content of 1.36 cmol $kg^{-1}$, while that of plot treated with NPK and PM (50%) + BC (50%) increased from 1.73 to 2.94cmol $kg^{-1}$. The soil in control plot had exchangeable K content of 0.41cmol $kg^{-1}$, while that of plot treated with NPK and PM (50%) + BC (50%) increased from 0.44 to 0.55cmol $kg^{-1}$. Results from the physical analysis of the soil after harvesting, shows that NPK had the highest clay content (14.0%) while PM (50%) + BC (50%) at 10 t/ha had the lowest clay content (8.0%), control had the highest silt content (12.00%) while PM (50%) + BC (50%) at 15 t/ha and NPK had the lowest silt content (9.0%), PM (50%) + BC (50%) at10 t/ha had the highest sand content (81.0%) while NPK had the lowest sand content (77.0 %)

**Table 21: Residual physico-chemical analysis of the soil after the first planting on the field**

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at

| Treatment | pH ($H_20$) | Available P mg kg$^{-1}$ | OC | N | Ca | K | Clay | Silt | Sand |
|---|---|---|---|---|---|---|---|---|---|
| | | | g kg$^{-1}$ | | cmol kg$^{-1}$ | | | (%) | |
| Control | 6.38e | 11.6d | 0.88c | 0.10c | 1.36e | 0.41d | 10.8c | 12.0a | 78.0c |
| PM(50%)+BC(50%) at 10t/ha | 7.04c | 56.8a | 0.81d | 0.09d | 2.83b | 0.44c | 8.0e | 11.0b | 81.0a |
| PM(50%)+BC(50%) at 15t/ha | 7.75a | 54.7b | 1.03b | 0.11b | 2.66c | 0.55a | 13.0b | 9.0c | 78.0c |
| PM(50%)+BC(50%) at 20t/ha | 7.05b | 56.8a | 1.35a | 0.15a | 2.94a | 0.54b | 10.0d | 11.0b | 79.0b |
| NPK (100 kg N/ha) | 6.55d | 11.8c | 0.27e | 0.03e | 1.73d | 0.44c | 14.0a | 9.0c | 77.0d |

5% probability level.

Legend:

PM -poultry manure, BC -biochar

## 4.6 Effect of biochar supplemented with poultry manure on the growth and yield parameters of Amaranthus during the second planting on the field

### Plant height

Table 22 shows the response of plant height of Amaranthus to application of biochar supplemented with poultry manure and NPK during the second planting on the field. There was a general increase in the mean plant height throughout the growing period and there was significant difference among all the treatments. At 2 weeks after planting (WAP), PM (50%) + BC (50%) at 20 t/ha had the highest plant height followed by PM (50%) + BC (50%) at 15 t/ha and were significantly ($p< 0.05$) different from NPK and control. However, there was no significant difference between PM (50%) + BC (50%) at 10 and 15 t/ha respectively. At 4 weeks after planting (WAP), PM (50%) + BC (50%) at 15 t/ha had the highest plant height of 36.7cm and was significantly ($p< 0.05$) different from other treatment including NPK and control. However, at 6 weeks after planting (WAP), the plant height of Amaranthus that received PM (50%) + BC (50%) 20 t/ha showed the highest means of 50.3cm, followed by PM (50%) + BC (50%) at 15 t/ha (50.0cm) and PM (50%) + BC (50%) at 10 t/ha (47.0cm) and these were significantly ($p< 0.05$) different from NPK and control.

**Number of Leaves**

Table 23 shows the response of number of leaves of Amaranthus to application of biochar supplemented with poultry manure and NPK during the second growing period on the field. At 2 weeks after planting (WAP), there was no significant difference between the numbers of leaves of Amaranthus grown among the treatments; PM (50%) + BC (50%) at 10, 15, 20 t/ha and NPK. At 4 WAP, the number of leaves in PM (50%) + BC (50%) at 15, was significantly ($p < 0.05$) higher than number of leaves from all other treatments and NPK including control. However, at 6 WAP, PM (50%) + BC (50%) at 15 t/ha produced the highest number of leaves (39.7) and was significantly ($p < 0.05$) higher than number of leaves from all other treatments including NPK and control.

**Table 22: Plant height of Amaranthus as influenced by application of biochar supplemented with poultry manure during the second planting on the Field**

| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | cm | | |
| | 2 | 4 | 6 |
| Control | 2.6d | 17.7d | 28.2b |
| PM(50%)+BC(50%) at 10t/ha | 3.3bc | 30.3b | 47.0a |
| PM(50%)+BC(50%) at 15t/ha | 3.8ab | 36.7a | 50.0a |
| PM(50%)+BC(50%) at 20t/ha | 4.1a | 24.0c | 50.3a |
| NPK (100 kg N/ha) | 2.9c | 21.2c | 28.2b |

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level.

Legend:

PM -poultry manure

BC -biochar

**Table 23: Number of Leaves of Amaranthus as influenced by application of biochar supplemented with poultry manure during the second planting on the Field**

| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | 2 | 4 | 6 |
| Control | 3.7b | 19.3c | 27.3c |
| PM(50%)+BC(50%) at 10t/ha | 4.3ab | 20.0c | 31.3bc |
| PM(50%)+BC(50%) at 15t/ha | 5.3a | 32.7a | 39.7a |
| PM(50%)+BC(50%) at 20t/ha | 4.7ab | 26.0b | 32.0b |
| NPK (100 kg N/ha) | 4.0ab | 20.0c | 27.7bc |

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level.

Legend:

PM -poultry manure

BC -biochar

### Stem Girth

Table 24 shows the response of stem girth of Amaranthus to application of biochar supplemented with poultry manure and NPK during the second growing period on the field. At 2WAP, PM (50%) + BC (50%) at 20 t/ha was significantly ($p < 0.05$) different to NPK and control. However, there were no significant difference between PM (50%) + BC (50%) at 10, 15 and 20 t/ha. At 4 WAP the stem girth of Amaranthus treated with PM (50%) + BC (50%) at 15 and 20 t/ha were significantly ($p< 0.05$) higher than stem girth produced from NPK and control. However, at 6 WAP, Amaranthu*s* stem girth with values of 3.77 mm produced from PM (50%) + BC (50%) at 15 t/ha was significantly ($p< 0.05$) higher than all other stem girth produced from other treatments including the control. PM (50%) + BC (50%) at 15 t/ha produced the highest stem girth while control had the smallest stem girth.

### Amaranthus Yield

Figure 5 shows the Amaranthus yield produced from application of biochar supplemented with poultry manure and NPK during the second growing period on the field. PM (50%) + BC (50%) at 15 t/ha had the highest yield of 12.6 t/ha, followed by PM (50%) + BC (50%) at 20 t/ha (8.50 t/ha), PM (50%) + BC (50%) at 10 t/ha (4.30 t/ha), NPK (6.0 t/ha) and control respectively (1.60 t/ha). Therefore PM (50%) + BC (50%) at 15 t/ha was significantly ($p< 0.05$) different from all other treatment including NPK and control.

**Table 24: Stem Girth of Amaranthus as influenced by application of biochar supplemented with poultry manure during the second planting on the Field**

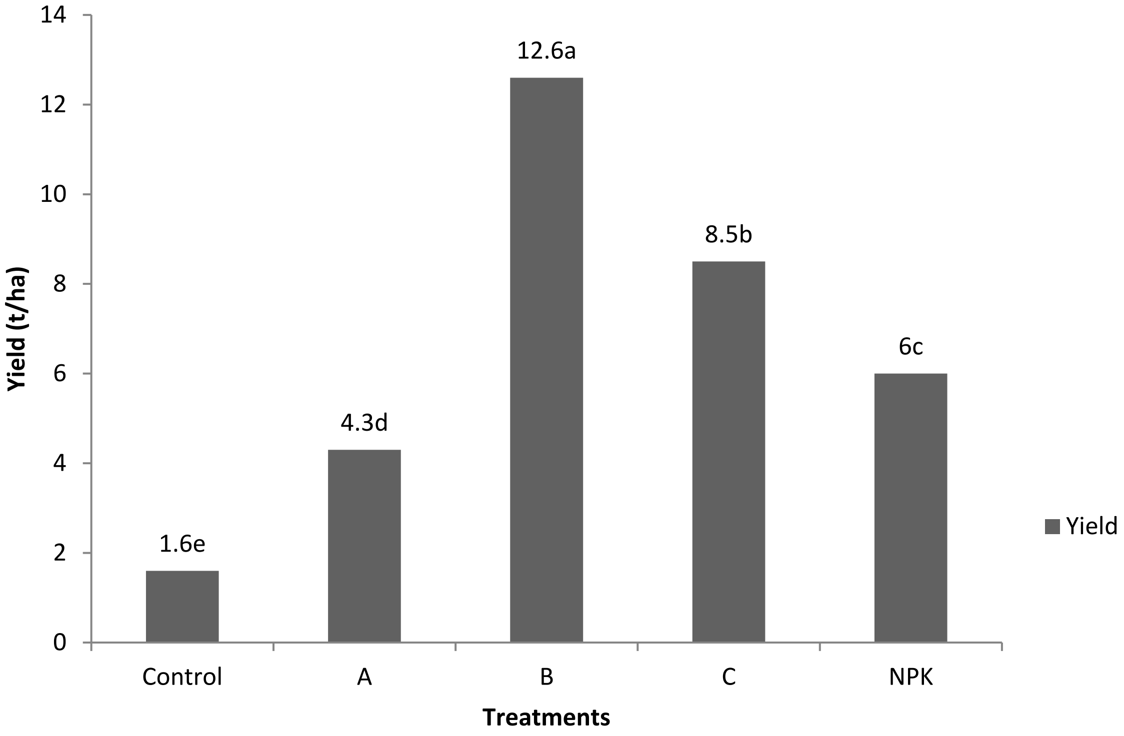
| Treatment | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | mm | | |
| | 2 | 4 | 6 |
| Control | 1.07c | 1.43c | 2.40c |
| PM(50%)+BC(50%) at 10t/ha | 1.97ab | 2.50ab | 3.03b |
| PM(50%)+BC(50%) at 15t/ha | 2.10ab | 2.97a | 3.77a |
| PM(50%)+BC(50%) at 20t/ha | 2.30a | 2.90a | 3.17b |
| NPK (100 kg N/ha) | 1.63bc | 2.27b | 2.67bc |

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level.

Legend:

PM -poultry manure

BC –biochar



Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level

**Figure 5. Effect of biochar supplemented with poultry manure and NPK on yield of Amaranthus during second planting**

Legend:

A - PM(50%)+BC(50%) at 10 t/ha

B- PM(50%)+BC(50%) at 15 t/ha

C- PM(50%)+BC(50%) at 20 t/ha

PM -poultry manure

BC –biochar

**Physico-chemical analysis of the soil after the residual harvesting**

The effects of application of different rates of biochar supplemented with poultry manure and NPK on the experimental soil after residual harvest are presented in Tables 25. The pH value ranged from 7.88 in NPK and PM (50%) + BC (50%) at 20 t/ha plots to 8.15 in PM (50%) + BC (50%) at 15 t/ha plot. Application of NPK reduces soil pH value than other treatment including control. Soil available P content in soil ranged from 8.2 mg $kg^{-1}$ in control plot to 55.5mg $kg^{-1}$ in PM (50%) + BC (50%) a 15 t/ha, which was higher than the plot treated with PM (50%) + BC (50%) at 10, 20 t/ha and NPK. Soil organic carbon ranged from 0.36 g $kg^{-1}$ in control and NPK plot to 3.36 g $kg^{-1}$ in plot with PM (50%) + BC (50%) at 15 t/ha. There is a general increase in the values of organic C from control and NPK to other treatment. Total N varied between 0.04 g $kg^{-1}$ in control and NPK and 0.37 g $kg^{-1}$ in PM (50%) + BC (50%) at 15 t/ha plot. The soil in control plot had exchangeable Ca content of 1.36 cmol $kg^{-1}$, while that of plot treated with PM (50%) + BC (50%) and NPK increased from 2.21 to 2.74 cmol $kg^{-1}$. The soil in control plot had exchangeable K content of 0.34cmol $kg^{-1}$, while that of plot treated with PM (50%) + BC (50%) and NPK increased from 0.26 to 0.37cmol $kg^{-1}$. Results from the physical analysis of the soil after harvesting, shows that control had the highest clay content (11.00%) while NPK had the lowest clay content (7.00%), silt content varies across the plot from 11.00% to 12.00%, NPK had the highest sand content (81.00%) while control had the lowest sand content (78.0%).

**Table 25: Physico-chemical analysis of the soil after the second planting on the field**

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at

| **Treatment** | **pH**<br>**($H_2O$)** | **Available P**<br>**mg $kg^{-1}$** | **OC** | **N** | **Ca** | **K** | **Clay** | **Silt** | **Sand** |
|---|---|---|---|---|---|---|---|---|---|
| | | | **(%)** | | **cmol $kg^{-1}$** | | **(%)** | | |
| Control | 7.99c | 8.2e | 0.36d | 0.04d | 1.36e | 0.34d | 11.00a | 11.00b | 78.00d |
| PM(50%)+BC(50%) at 10t/ha | 8.07b | 42.8c | 0.63c | 0.07c | 2.50c | 0.26e | 9.00c | 12.00a | 79.00c |
| PM(50%)+BC(50%) at 15t/ha | 8.15a | 55.5a | 3.36a | 0.37a | 2.74a | 0.37a | 8.00d | 12.00a | 80.00b |
| PM(50%)+BC(50%) at 20t/ha | 7.88d | 45.6b | 1.05b | 0.12b | 2.60b | 0.35c | 10.00b | 11.00b | 79.00c |
| NPK (100 kg N/ha) | 7.88d | 11.2d | 0.36d | 0.04d | 2.21d | 0.36b | 7.00e | 12.00a | 81.00a |

5%

probability level.

Legend:

PM -poultry manure… BC -biochar

# CHAPTER FIVE

## 5.0 DISCUSSION

The major limiting factor facing crop production in the tropics is the deficiency of soil nutrients resulting from land degradation and this affects the growth, nutrient content, and uptake of the plant. Low levels of nitrogen, phosphorus, and organic carbon were characteristic of the soil used for this experiment as shown in the physicochemical analysis of the soil carried out prior to planting (Table 2) and the finding corroborates with the earlier results of Aduayi *et al.* (2002) who reported that most soils in Nigeria are deficient in nitrogen, phosphorus, and potassium and sometimes organic matter. Therefore, a sustainable method of improving the nutrient base of the soil should be employed to enhance the growth and nutrient content of the plant.

The findings of the study revealed that at different fertilizers rate, there is significant effects on Amaranthus growth for both first and regrowth in the screenhouse and also for first and second planting on the field. Observations on the height, number of leaves and stem girth of the Amaranthus plants from 2 to 6 WAP showed that although other rates of application improved the growth parameters significantly, however, PM (50%) + BC (50%) at 20t/ha and PM (50%) + BC (50%) at 15t/ha for the screenhouse and field experiment respectively, had the greatest positive effects on the vegetative growth of the plants than the other fertilizer rates used. This may be as a result of better nutrient mineralization with time of application. This is in line with the findings of several researchers such as Gabrielle *et al.*

(2004), Olowoake (2014) and Ayanfeoluwa *et al.* (2015) that the nutrients present in organic fertilizers have the properties of being released slowly, which leads to reduction in soil nutrient losses.

The supplement of biochar with poultry manure significantly improved the yield of Amaranthus, this could be attributed to the high carbon content of both biochar and poultry manure which could have similar impacts on soil nutrients and structure. Both amendment increased nitrogen and phosphorous. Therefore, the combined effects of the amendments could explain the observed results. According to Schulz and Glaser (2012), application of biochar in combination with organic or inorganic fertilizers could have significant ($P < 0.05$) synergistic effect on plant growth. Asai *et al.* (2009) also stated that the combination of biochar with other organic material will promote the productive management for crop production. However, the effect of biochar on organic matter dynamics can be very variable, dependimg on the different types of soil, experimental duration and type of biochar (Wang *et al.,* 2015). Several studies have demonstrated increased supply of nutrients when biochar was applied in combination with other organic manure, ultimately increasing crop yield and biomass (Kammann *et al.,* 2015; Agegnehu *et al.,* 2016; Bass *et al.,* 2016). Liu *et al.* (2012) showed that the combined application of compost and biochar had a positive synergistic effect on soil nutrient content under field conditions.

The screenhouse study revealed that PM (50%) + BC (50%) at 15 t/ha increased soil productivity and led to higher Amaranthus yield than using mineral fertilizer in the first and second planting, this may be as a result of the presence of organic carbon, N, P, and K in the biochar and poultry manure and also their slow and steady release into the soil as seen in the physicochemical analysis of the various soils after both planting.

The field study also revealed that PM (50%) + BC (50%) at 20 t/ha led to higher Amaranthus yield than other treatment in the first and second planting, this may be as a result of the presence of organic carbon, N, P, and K in the biochar and poultry manure and the nutrient uptake by the plants (Table 7 and 14)

Figure 4 and 5 showed that PM (50%) + BC (50%) at 15 t/ha had the highest yield of 8.6 t/ha and 12.6 t/ha at first planting and at residual effect respectively, Olowoake and Ojo, (2014) reported that the highest yield of Amaranthus using organomineral fertilizer has 18.9 t/ha and 7.5 t/ha has at first planting and at residual effect respectively, this is as a result of high nutrient element (N, P, K) in organomineral fertilizer compare to biochar and poultry manure. Biochar helps the soil to retain and preserve nutrients and fertilizer (Lehmann *et al.,* 2006) even also from other sources; poultry manure helps in nutrient availability and high crop yield (Adeleye *et al.,* 2010). Difference in nutrient content or rate of the treatments and available nutrient in the soil can affect the yield of crop growth. Calcium (Ca) and potassium (K) were significantly increased as a result of biochar and poultry manure addition. The increase can be attributed to the high organic matter content from the poultry manure and to the small labile carbon components of biochar. Organic matter is a reservoir of nutrients that can be released to the soil. Thus, soils with high amount of organic matter typically have higher cation exchange capacity (CEC), that is, are able to bind more cations such as Ca, K and Mg (Reeves, 1997; Wettersted *et al.,* 2009).

According to Topoliantz and Ponge (2005); Yamato *et al.* (2006) and Rajkovick *et al.* (2012), Ca, K and Mg maybe directly introduced to the soil through labile organic compounds associated with biochar and become available as these compounds decompose. Previous studies have shown that biochar increase soil nutrients through its high porous structure, large surface area and negative charge (Bird *et al.,* 2008; Cheng *et al.,* 2008; Novak *et al.,* 2009). Also amendment of soil using poultry manure improved soil Ca, K and Mg in soil (Adeniyan and Ojeniyi, 2005; Ayeni *et al.,* 2008; Okonwu and Mensoh, 2012; Adekiya and Agbede, 2017), attribute the increase to the availability and adequate supply of organic matter by poultry manure.

The combination of biochar with poultry manure significantly increased soil total nitrogen and soil total available phosphorus. The increase could probably be due to the retention of labile nutrients from poultry manure on biochar pores (Kanthle *et al.,* 2016). According to Laird, (2008) the combination of biochar with poultry manure may ameliorate some of the limitations associated with manure application in the soil. Moreover, biochar has been shown to absorb nutrients and protect them against leaching (Major *et al.,* 2009). According to Luo *et al.* (2011), biochar contains nitrogen which can increase soil nitrogen directly or through effects of priming and can therefore improve the bioavailability of soil nitrogen. In addition, both amendments modified physical properties and added nutrients. These would have encouraged activity of microbes and decomposition of materials, mineralizing phosphorous availability at higher rates. Moreover, the combination of biochar and poultry manure supplied more phosphorous to the soil than other treatment.

There is also an increase in the pH of the soil at both first and second planting, biochar induced increases in soil alkalinity (liming). According to Cui *et al.* (2011), liming agents reduce the concentration of iron and aluminum in the soil and the previous bound phosphorous then become available. Steiner *et al.* (2008) found that biochar was most effective at changing the soil pH in acidic soils, which would be particularly beneficial in low latitudes where soils are acidic and agriculture is limited by phosphorus availability. Application of biochar supplemented with poultry manure resulted in a significant increase in soil organic carbon. The increase in soil organic carbon could probably be due to the direct addition of carbon from the biochar since biochar is a carbon source and also the direct addition of organic matter since soil organic carbon is the main constituent of soil organic matter. According to Lehmann and Joseph (2015) a small portion of biochar is available for microbial decomposition and most of the remaining recalcitrant carbon contributes directly to long-term carbon sequestration in soil. According to Ojeniyi (2000), poultry manure has the ability to increase soil organic matter content. The authors indicated that the increase in soil organic carbon was expected, since organic manures have the ability of increasing soil organic matter content (Ojeniyi, 2000).

The interactive effect of biochar and poultry manure in increasing soil chemical properties can be explained by the fact that addition of poultry manure to biochar may facilitate surface oxidation of biochar by elevated temperature and may also change biochar properties biotically by the high microbial activity or the cometabolic decay during the degradation of available carbon sources (Hamer *et al*., 2004; Kuzyakov *et al.,* 2009).

Biochar absorbs leachate generated during the process, resulting in increased moisture content. With the leachate, biochar also absorbs organic matter and nutrients, resulting in increased concentrations of water-extractable organic carbon, total soluble nitrogen, plant-available phosphorus and plant-available potassium, therefore increasing nutrient retention capability of the soil (Jia *et al*., 2018).

The response of nutrient uptake of Amaranthus to application of biochar and poultry manure was consistent with the values of soil chemical properties recorded for these treatments. There was increased nutrient availability in the soil as a result of application of biochar supplemented with poultry manure leading to increased uptake by Amaranthus plant. This indicated that biochar amended with poultry manure is good for the vegetable farmers to use as soil amendments. Moreover, this soil amendment could reduce, to some extent, dependence on chemical fertilizers and in this way could improve nutrients and water retention in the soil.

# 6.0 CONCLUSION AND RECOMMENDATION

Fertilizer is a very essential input in crop production. The achievement of self-sufficiency in food and raw materials for industrial programmes requires that the country should be able to produce at least 80 % of its fertilizer required internally to assure adequate and timely availability.

This study was conducted to solve some of the problem associated with the high costs and non-availability of the inorganic fertilizer to meet the demand of small scales farmers. In view of this, there is a need to search for alternatives to inorganic fertilizer. Abundant wastes (agricultural and industrial) in our society together can cause environmental and economic implications. The common technology for increasing fertilizer efficiency is integrated crop management which includes the application of organic manure and other organic materials to soil

This study intends to examine the effects of biochar supplemented with poultry manure on growth of *Amaranthus caudatus*, nutrient uptake and soil properties. The results showed that biochar supplemented with poultry manure significantly improved soil physical and chemical properties as well as Amaranthus yield.

The results of this study are summarized and concluded as follows;

1) Biochar supplemented with poultry manure used in this study contribute positively to the growth, nutrient uptake, yield of the Amaranthus and properties of the soil; this suggests that biochar enriched with poultry manure have a high potential than NPK for building up residual nutrients in the soil with time.

2) The post planting pH of the experimental soil increased among the biochar supplemented with Poultry Manure used in both pot and field study for first and second planting respectively. This portrays increase in the base saturation and availability of a wide range of essential nutrients released from the applied organic fertilizers to the crops for optimum growth.

3) Biochar amended with poultry manure at 20 t/ha has potential to support plant regrowth because the nutrient contents in the soil reflected in plant height, stem girth, number of leaves and dry matter yield in the screenhouse

4) There was positive response to the biochar amended with poultry manure application during the first planting and second planting. The plots with PM (50%) + BC (50%) at 10 t/ha, 15 t/ha and 20 t/ha did better than the plot fertilized with NPK mineral fertilizer.

5) The effect of treatment PM (50%) + BC (50%) at 15 t/ha on soil fertility was positive, it increased the soil Available P, N, Exchangeable K, Organic Carbon of the soil after harvesting at first and second planting in the field compared with NPK treatment.

In summary, from this study it can be deduced that biochar supplemented with poultry manure can serve as an alternative to mineral fertilizer. Furthermore, application of biochar amended with poultry manure increased soil productivity and led to higher Amaranthus yield than using NPK 15-15-15.

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