PRODUCTION OF BIOVHAR FOR SOIL ENRICHMENT, PARAMETRUC AND SENSITIVITY ANALYSIS ON THE YIELD OF SPINACH (*Amaratus Calacatus*)

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Abstract

This research is aimed at enriching soil using biochar produced from saw dust (pine wood). Degradation of soil is a major challenge faced by farmers which must be curtailed. These challenges can be minimized when degraded soil is amended with biochar. Biochar enriches soil with nutrients and boost the yield of spinach. To achieve this aim, biochar was produced from pine wood at pyrolysis conditions of temperature: 300 ºC, 350 ºC, 400 ºC, holding time of 30 mins, 60 mins and 90 mins to get the yield and nutrient content. The result of the pyrolysis shows the biochar produced at 350^0C, holding time of 60 mins had the highest amount of Nitrogen and Carbon content. The pyrolysis condition was therefore regarded as the optimum condition for subsequent production of samples of biochar for further analysis and characterization. Proximate and ultimate analysis was conducted on the sample of the biochar produced at optimum pyrolysis conditions, it showed that biochar contained a moisture content (4.32%), ash content (26.12%), volatile matter (35.32%) and fixed carbon (34.34%). The ultimate analysis result revealed that biochar contains carbon content (72.45%), hydrogen (2.66%), Oxygen present was 13.02% and 3.60% Nitrogen which is 100% higher than that obtained from the raw saw dust. The sulphur content was found to be less than 0.1%. The Brunauer-Emmet Teller (BET) result show that the surface area of the biochar had increased from 1.384 m^2/g obtained from the saw dust to 591.0 m^2/g, pore volume (0.1747 cc) and pore size (6.077nm) for saw dust and the biochar respectively. The scanning Electron Microscopy (SEM) was conducted and the result shows that the biochar produced is porous in nature, while the X-ray diffraction pattern (XRD) revealed the amorphous nature of the biochar. Field application of biochar produced was carried out to determine its effect on the growth of spinach. Prior to this application, soil analysis was conducted before planting and after harvesting, and the result revealed an increment of about 70% in nitrite and soil pH increased sharply. Parametric and sensitivity test conducted on the yield of spinach revealed an increase in the plant height (42.46 cm) in the treatment with biochar as compared to the control (41.10 cm). The stem girth increased in the treatment with biochar (4.69 cm) as compared with control (4.10cm). Total yield per bed increased in treatment with biochar (3.4 kg) compared with control (3.2 kg). It could be deduced that the treatment with biochar application effectively enriched the soil for better spinach yield. It is recommended that nutrient analysis should be done spinach grown using biochar and fertilizer as enrichment.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Food safety has been a major challenge facing the Sub-Saharan region, there is need for this challenge to be addressed. Soil degradation poses a great threat to sustainability in food production. This challenge, worsening global pressure on normal resources, mainly on water, calls for essential changes in our food classification. To curb these challenges, feeding systems have to be simultaneously effective and flexible at all levels from the farm to the consumption level. They have to develop more effectively in reserve employment and become more capable to adapt to variations and impacts. For example, livestock and crop production are the most essential source to make living in Africa for nearly 61% of the working inhabitants (Lehman & Joseph, 2009). More than one third of the overall area of Africa is appropriate for agricultural improvement and development. Therefore, it is necessary to inform the farmers or peasants of the importance of biochar to improve soil and increase productivity by improving water and nutrient retention capacity and thereby decreasing over dependence on chemical fertilizers.

The study biochar for soil enrichment came from the possibility of proffering solution to the challenges presently facing world, these challenges are waste management, renewable energy management, soil declination and climate change (Sanchez, 2017). There are different stages for the extraction of renewable energy from feedstocks and biochar aids in building up soil fertility and food availability curtailing the challenges of soil fertility. Biochar poses a great importance in boosting soil fertility and controlling leaching away of soil nutrients. The concept of using biochar as a soil amendment may seem recent but it really comes from the study of very ancient soils in the basin of Amazon (Yuan *et al*., 2011). It is known that "Terra preta" or black soil of the Indians was designed by indigenous people since thousand years ago when they combined charcoal and different biomass, nutrient trash like animal bones and fish bones (Beckingham and Ghosh, 2016). Until today, black soil or "Terra Preta" soils remain more fertile than neighboring or surrounding unmodified soil. Researchers see that the charcoal (biochar) in these soils is the one that keeps them so fertile over such extensive stages in an environment that rapidly filters nutrients out of the soil and where organic materials decomposes so quickly (Yuan *et al*., 2011).

Biochar is a stable form of carbon created by heating biomass in a low or no oxygen environment. When used as a soil amendment, biochar has an extremely porous carbon structure which allows for effective water and nutrient storage, as well as providing a habitat for high quantities of soil microbes. Biochar forms a dynamic substrate, so it provides numerous benefits, including increasing nutrient availability, increasing soil water retention, improving crop yield, and sequestering carbon for hundreds to thousands of years.

However, biochar research has been concluded by many studies that biochar's effectiveness depends largely on the biomass feedstock and the soil to which it is applied. (Jaetzold & Schmidt, 2016a). Thousands of peasant farmers produce char by open burning of biomass thereby causing environmental pollution. This has been the conventional method used for ages by farmers causing more damage to the climate. This method of producing char has not proven to be very effective because production parameters cannot be considered using this method of producing biochar.

Biochar is grabbing more attention because it aids in improving crop growth and quality of soil while sequestering carbon in soil and providing other environmental advantages such as controlling greenhouse emission and solid waste management. It represents a tool management for quality of soil in the long run with climate change mitigation. Currently, scientific research on the environmental and agricultural scope of biochar is being published at growing rate (Steinbess *et al.*, 2016). However, biochar is the main ingredient in a new carbon-negative strategy to solve numerous ecological and agricultural problems. If properly made and used, biochar can relieve climate change and other environmental effects by increasing soil fertility and agricultural yields, sequester carbon, enhance soil structure, aid water penetration and aeration, and as well create local jobs and economic cycles.

1.2 Statement of the Research Problem

Soil degradation is a major challenge facing the agricultural sector, making the yield of crop to reduce and causing food insecurity.

Experimental researches have been carried out on the use of biochar at the pilot level to boost soil fertility, but only little has been reported on field application of biochar for soil enrichment, especially its effects on the yield of spinach.

1.3 Research Aim and Objectives

The aim of this research is to enrich the soil property using biochar for agricultural purposes which would be achieved through the following objectives:

i. Produce Biochar from saw dust through pyrolysis and characterize the produced Biochar through the following analysis (proximate and ultimate analysis, BET Analysis, SEM, XRD Analysis, CEC Analysis).

ii. Apply biochar to enrich soil using the broadcasting method.

iii. Evaluate its effect on plant growth (Spinach).

1.4 Scope of the Research Study

The scope of this research work is limited to the production of biochar for soil enrichment and analysing their effects on agronomy properties of Spianch (*Spinacia oleracea. L*).

1.5. Justification of the Research Study

Biochar is a promising resource for soil enrichment, being a renewable energy resource and due to its environmental friendliness. Biochar therefore poses great merits for agricultural technology used for soil enrichment.

This research targets field experiment of biochar and its agricultural benefits which has been less reported over the years

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil Enrichment

Enriching soil and biomass with saw dust is recommended at the international level as a way to boost soil productiveness, fertility and also to mitigate climate change. Biochar employed to improve land scope and impound carbon is attracting a great deal of attention. Its characteristics of chemical, physical and biological properties, containing big surface area, CEC (Cation Exchange Capacity), high water-holding capacity, size of pore, volume, distribution, and element composition, affect its recognized influences, particularly on microbial communities, these are discovered in lands remediation and composting (Novak *et al*., 2009). However, incomplete information existed about biochar for several farmers or peasants in agriculture scope. Therefore, farmers or peasants and gardeners are facing new opportunities and defiance each day, from feeding global extending and expanding population, whilst meeting severe new emissions requirements, to create more food on fewer land area while reducing their environmental emissions (Havlin *et al*., 2015). Widespread application and utilization of biochar in agricultural scope, forestry production, energy, environmental protection and additional areas, has boosted awareness by scientists and investigators inside and/or outside the country. This work would aid to provide a guide for the farmers or peasants and gardeners with an essential information about biochar and what the ability of biochar can be achieved in the soil, and which can provide the scientific reference for the biochar application, and to get high yield and good quality of crops in all of different types of soils.

There is need for the challenges of food security to be addressed by ensuring food safety through increased income and productivity, adapting to climate change and contributing to climate change mitigation (Ameloot *et al*., 2013). The challenge of soil degradation is worsening global pressure on normal resources, mainly on water, will need essential changes. To treat these challenges, feeding systems have to be properly designed and flexible at each level from the farm to the consumption level. They have to be effective in developing proactive solutions to solve all the problems of climate change, impacts and variations (Angst & Sohi, 2012). For example, in 1990s, livestock and cultivation increasing were the most important sources to make living in the Sudan for nearly 61% of the working inhabitants (Jensen *et al*., 2015). More than one third of the overall area of Sudan is appropriate for agricultural improvement and development. Therefore, it is necessary to inform the farmers or peasants of the importance of biochar to improve soil and increase productivity by improving water and nutrient retention. The motivation to study biochar came from the soil possibility to remedy many of the challenges fronting the today's world: waste administration, renewable energy, soil declination, and climate change. Different several other stages for the extraction of renewable energy from feed stocks, biochar builds up soil fertility and food availability rather than act as a challenging benefit. If suitably understood and applied, biochar has the possibility for generating several dissimilar win conditions with a few disadvantages (Cornelissen ***et al*.,** 2005). The concept to use biochar as a soil amendment may seem recent but it really comes from the study of very ancient soils in the Basin of Amazon (Glaser ***et al*.,** 2010). It is known that "Terra preta de Indio", or "black soil of the Indians" was designed by indigenous peoples since thousands of years ago when they amassed charcoal and a different waste, nutrient trash like animal bones and fish bones. Until today, black soil or ''Terra preta'' soils remain more fertile than neighbouring or surrounding, unmodified soil (Stenbeiss *et al.,* 2016). Researchers see that the biochar in these soils, is the one that keeps them so fertile over such extensive stages in an environment that rapidly filters nutrients out of soil and where organic materials decompose so quickly.

2.2 Biochar

Biochar is the carbon products gained from raw materials, like forest, animal compost, and plant residues heated in a closed storage place without air. In many technical and clearer standards, biochar is created by the thermal decomposition of organic substance below incomplete supply of (O_2) oxygen, and at comparatively low temperature (<700 ˚C), the feedstock's heats up to the point at which pyrolysis starts. At this point, the reaction becomes exothermic, that means it starts to create heat and no longer consumes it (Liang *et al*., 2015). The expression "Biochar" is a moderately contemporary improvement, evolving in combination with soil managing, carbon confiscation or sequestration matters, and immobilization of contaminants (Hollister, 2011), peasants or farmers must be aware of this. Biochar retains the formation or structure of the biomass and can be very porous with a very great surface area (Kameyana *et al*., 2012).

2.2.1 Properties of biochar

The properties of biochar can change extensively, depending on what the biochar is prepared from and how it is formed. Some biochar can characteristics which make them excellent amendment in one soil but not in another soil (Beesley *et al.,* 2010).

Biochar with Large surface area has many beneficial effects on soil fertility by increasing its CEC, biological activity, water and air circling in the soil. Large surface area is enhanced by considerable proportion of pores and results in high CEC (Lehmann and Joseph, 2009), as well as enhanced biological activity (Steiner *et al.,* 2014).

However, some researchers have found contrary results showing a decrease in microbial biomass carbon after biochar addition (Olsson *et al.,* 2013). Another valuable property of biochar is suppression of emissions of greenhouse gases in soil. It has also been demonstrated by (Yuan *et al.,* 2011) 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. (Bostrom *et al.,* 2014) 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. (Bostrom *et al.,* 2014) 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 power of biochar is attention-grabbing because it has been established and demonstrated to increase crop outgrowth and quality of soil (Beesley and Marmiroli**,** 2011), while sequestering carbon in soil and providing other environmental advantages. As such, it represents a tool management for quality of soil on the long period, with climate change mitigation. Presently, scientific research study on the environmental advantages and agricultural scope of biochar is being published at growing rate (Cheng *et al.,* 2016).

However, biochar is the main ingredient in a new carbon-negative strategy to solve the numerous critical current ecological, economic and energy deficiencies (Khan *et al.,* 2014).

2.2.2. Cation exchange capacity.

Cation Exchange Capacity (CEC) is an important measure of the productivity and quality of soils, as it measures exchangeable cations, such as $Ca^{2+,}$ Mg^{2+}, K^{+}, and Na^{+} (Jaeztold and Schmidt, 2016b). CEC is also important in the prevention of nutrient leaching and water retention (Cheng *et al*., 2016). Plants generally uptake nutrients as simple ions in solution, however in cases where that solution is depleted, exchange desorption allows adsorbed cations to be exchanged, providing a reserve to replenish the solution (Beesley *et al.,* 2010). The CEC of biochar increases with age, due to abiotic oxidization effects in the soil; (Cheng *et al.,* 2016) found that when incubated at 70 ^{O}C for 4 months biochar and biochar-soil mix increased in CEC by 58% and 28% respectively.

2.2.3. Agricultural advantages of biochar

In a lot of pot studies, biochar has been shown to get better crop yields when compared to suitable controls where biochar was not applied (Lehmann and Joseph, 2009).

Biochar has caused very high yield enhancements on very poor soils such as acidic humid and tropical soils, in some instance increasing yields by factors of two or more. In more fertile soils, more modest developments in the range of 10% are common. Biochar does not comprise any appreciable quantities of existing nitrogen, but does comprise some decomposable carbon. So, if biochar is applied and deficient nitrogen is supplied, nitrogen immobilization can happen and decrease crop yields (Beckingham and Ghosh, 2011). This also occurs with compost, for example: if the ratio of Carbon to Nitrogen (C: N) is too high. Biochar is a soil improvement that is to be used along with applicable sources of nutrients, like animal composts, green manures, composts and fertilizers (Ameloot *et al.,* 2013). It is not a replacement for these inputs. Though the ash in biochar improves nutrients to plants, several biochar comprises only small quantities of ash. Also, any nutrients in ash not used by plants in the year after application are finally lost from the soil, sometimes quickly, for example by leaching farms and gardens (Angst and Sohi, 2012).

2.2.4 Applications of biochar

Several studies in temperate climates and tropical have established biochar capability to enhance plant growing, decrease discharge or leaching of nutrients. (Bandosz and Petit, 2016) retention of water, and augment microbial activity. It is very important to know that biochar is not an actual fertilizer but contains some ash and ash can provide nutrients to plants, for example (Ca) Calcium, (k) Potassium, and (Mg) Magnesium. These nutrients are frequently limiting in very poor soils. Majority cases of reduced plant growth due to biochar utilization can be imputed to provisional levels of pH, mobile matter (MM) and imbalances associated of nutrient with new biochar (Betts *et al*., 2013). Biochar frequently can have a firstly high (alkaline) pH, which is attractive when employed with acidic, and degraded soils, however, if pH value becomes too alkaline, plants might undergo nutrient insufficiencies. High quality production practices can reduce the quantity of mobile matter in the biochar. Microbial action can decompose and convert the carbon rich mobile matter into nutrients for plants, however, the microorganisms need (N) Nitrogen & additional soil elements, making them provisionally unavailable for uptake by plants (Chan *et al*., 2017). These transitional imbalances are afterwards corrected as mobile matter decomposes, unavailable nutrients are released and pH neutralizes. On the other hand, some study has demonstrated that biochar improvement to soil can result in a release of dissolved organic matter from soil as well as change the dissolved organic matter composition (Gou and Rockstraw, 2017). A rise in soil pH upon the addition of alkaline biochar, probable affected by alkaline ash found in biochar, clarified most of the observed release of dissolved organic matter.

Biochar comprises stable matter, ashes, unstable matter & moisture. Ashes comprise plant nutrients which can advantage plant growing in short period. The quantity or amount of ash in biochar can differ a lot (Ding *et al*., 2010). Biochar made from animal manures generally contain great sizes or proportions of ash, compared to biochar made from plant parts. Care must be taken when working with high ash biochar. It is probable or possible to induce salt stress in the crop if too much is applied at once (Vanzwieten *et al*., 2013). Stable substance in biochar remains in soil over the long term and offers nutrient retention and other benefits to soil quality. Unstable substance decomposes in the months and years after biochar is added to soil (Amonette and Joseph, 2015).

2.2.5 Biochar production

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. It was reported that the production of biochar with high nutrients depends on the type of raw material used and pyrolysis conditions (Kameyama *et al*., 2012).

Feed stocks 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. A 40 wt. % yield of biochar from maize stover was obtained by Yip *et al*, (2010). The biomass used for the production of biochar is mainly composed of cellulose, hemicellulose, and lignin polymers. Among these, cellulose has been found to be the main component of most plant-derived biomasses, but lignin is also important in woody biomass. 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, generating oil and gases as by-products. 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 (Yuan *et al.*, 2011). 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 (Jones *et al.*, 2012 range remains 250–500°C. The type of biochar produced depends on two variables: 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 of (<550°C)**,** biochar has an amorphous carbon structure with a lower aromaticity than the biochar produced at high temperature (Glaser *et al*., 2010). High temperature leads to lower char yield in all pyrolysis reactions. (Cornelissen *et al.*, 2005) 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% (Kameyama *et al.*, 2012). The pyrolysis process can be shown as follows:

Biomass (Solid) → Biochar + Liquid or oil (tars, water, etc.)

+ Volatile gases (CO_2, CO, H_2)

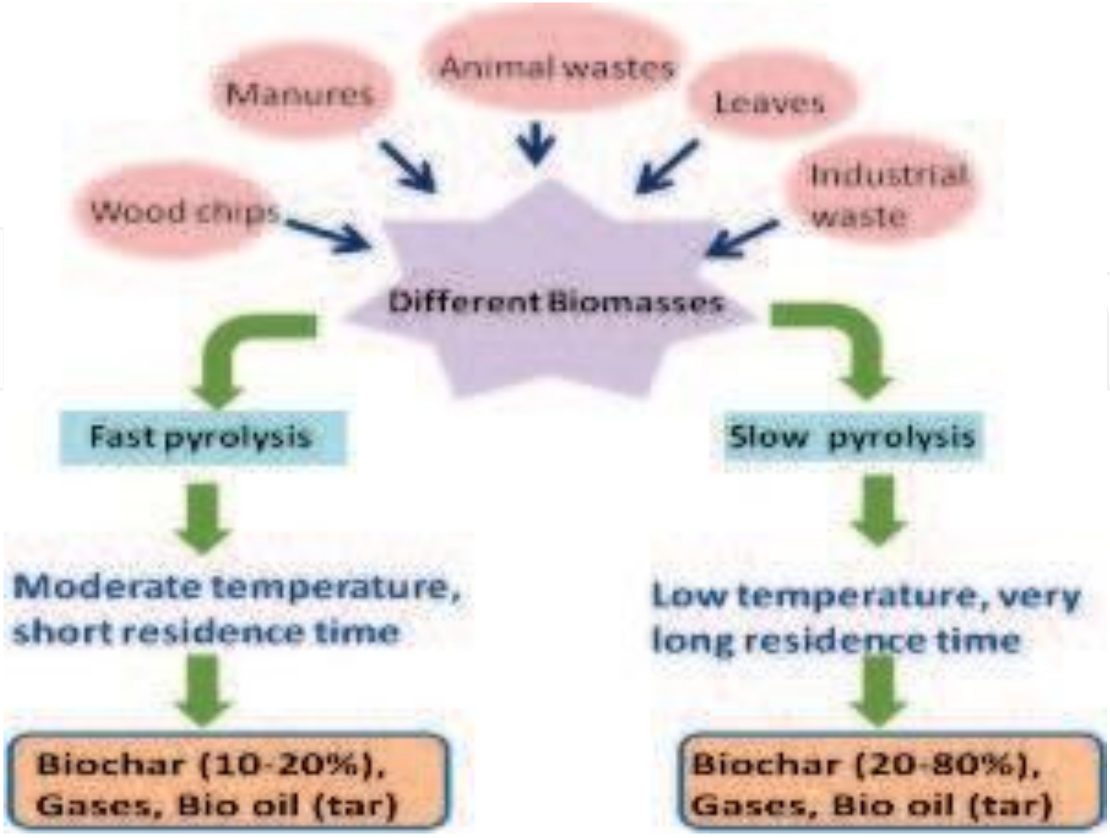

Figure 2.1. Pyrolysis Process of Biomass

Source: (Kameyama *et al*., 2012)

2.2.6 Types of pyrolysis used to produce biochar.

The pyrolysis process is separated into several distinct pyrolysis systems based on several factors. Chief among them are the feed stock, the residence time, and the heating rate of the biochar, which is partially also based on the particle size of the feedstock. Glaser *et al*, (2012) found that holding time and heating rate were the two factors with the most significant effect on biochar surface area and porosity. Higher temperatures tend to yield less char, and a lower heating rate tends to increase micro porosity.

2.2.7. Quantity of biochar for application

Most favourable application amount for biochar depends on the particular type of crop management and it is imperative to note that not all biochar is the same (Jensen *et al.*, 2015). The main physical and chemical properties of biochar are really affected by the kind of biomass being heated and the conditions of the pyrolysis method. For instance, biochar prepared from compost will have a greater nutrient substance or content than biochar prepared from wood (Nandwa, 2013). However, biochar prepared from wood might have a better stability (Mati, 2010). Two different biochar will look comparable but will behave completely in a different way. Several biochar resources, for example bones and manures, are mostly composed of ashes, and thus can provide considerable quantities of nutrients to crops. On the other hand, the Carbon (C) content of great inorganic ash biochar is low (<10%), therefore longer period nutrient retention purposes will be less for a given quantity of substance (Okalebo, 2018). Variability in soils and biochar resources, employers of biochar should think about analysing different amounts of biochar application on a few amounts before setting out to apply it on big areas. At this time there is insufficient data available to allow the determination of perfect biochar application rates in dissimilar soils and cropping systems (Frossard *et al.*, 2016). Many researches indicate that minor application of biochar yielded affirmative outcomes (Cornelissen *et al.*, 2016). Also, biochar can be applied incrementally and included with manure applications or fertilizer regimens applications. In field experiments published to date, rates of 2 - 22 t/ac (5 - 50 t/ha) have given favourable or positive results (Giron *et al.*, 2016). The maximum end of this range may not be feasible or practical in terms of biochar sourcing and incorporation to the soil and have considerably been used effectively or successfully.

The aim of applying biochar to soil fundamentally falls into four broad categories:

- Agricultural profitability
- Management of pollution and controlling hazard to environment
- Reposition of degraded land
- Sequestration of carbon from the atmosphere.

Basically, biochar made from grassland and forest wastes, makes it possible for biochar to persist for thousands years with a few decompose. Therefore, biochar has a long-lasting effect in soil, and that beneficial effects improve over time (Betts *et al*., 2013). Laboratory studies employing the modern methods evaluate that biochar has a mean residence time in soils to many thousand years. Biochar can be applied to soil by hand or using conventional machinery such as manure spreaders and lime, and should be thoroughly incorporated into the soil by tillage. In many cases, like perennial crops and other fruit orchards where ploughing is not an option, biochar can be:

1. Applied to the soil surface and preferably enclosed with other biological resources
2. Applied with compost or mulch

Used as a liquid slurry if delicately ground (on a big measure). However, biochar can increase microbial action and decrease nutrient damages through fertilizing or composting, biochar is charged with nutrients, wrapped with pH-balanced and microbes and content of MM (mobile matter) is decay into nutrients of plant (Karhu *et al*., 2011). Irrespective of the application techniques, it is very significant to be careful when dealing with dryish biochar, which is very dusty and should not be prevalence in conditions of wind. This can be simply treated by moistening the biochar earlier application. In order to respiratory protection should be worn dust mask when handling the dry substance. (Gaskin *et al.,* 2018).

2.2.8 Upgrading biochar for farm usage

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 mixing of biochar may improve the efficiency of manure and other amendments (Chan *et al.,* 2012). However, 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 (Liang *et al.,* 2015), 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. The effect of biochar on soil N cycle depends on the interaction between biochar characteristics and soil properties (Cheng *et al*., 2016).

The match of the right biochar with the right soil will achieve benefits, whereas arbitrary application of biochar without considering biochar and soil properties may induce irreversible negative consequences (Betts *et al*., 2013). Previous research studies investigated the effect of biochar on soil N cycle from a single perspective. However, whether biochar holds promise in benefiting soil N cycle and how to optimize biochar application under different effective adsorbent. The figure 2.2 illustrates soil N cycle of biochar application.

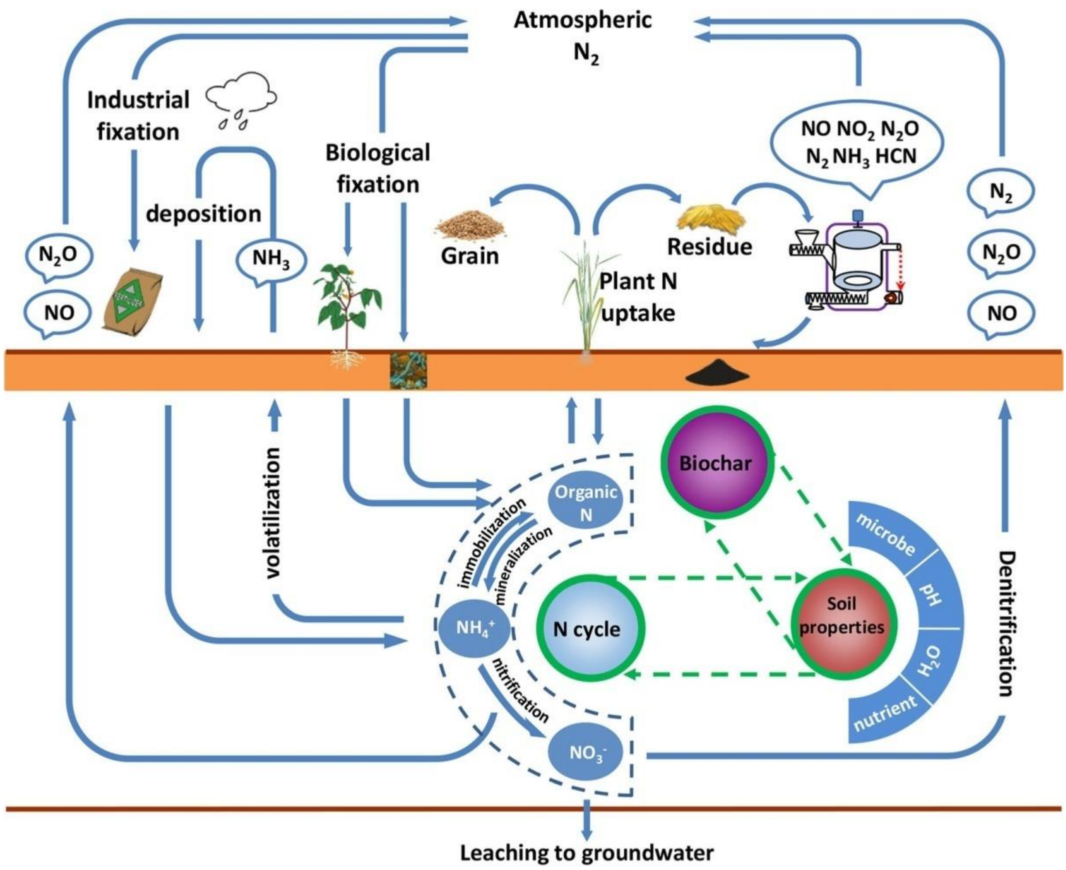

Figure 2.2. Soil N cycle of biochar application

Source: (Betts *et al*., 2013)

2.2.9 Nutrient properties of biochar

Biochar affects soil fertility in many ways; it can add nutrients by itself or make them more available for plant uptake by enhancing the decomposition of organic material- or, possibly, reduce decomposition rates of other organic material thereby increasing soil concentration in the long run. Moreover, the large surface area results in increased CEC, which may prevent nutrient leaching by sequestering it into its matrix and thus eutrophication (Lehmann and Joseph, 2009). Lehmann *et al*, (2013) found a significant decrease in leaching of applied fertilizers after charcoal addition. Further, improved plant uptake of P, K and Ca was observed, by increasing CEC, applied fertilizers can be adsorbed to the surface area and thereby used more efficiently by plants (Steinbeiss *et al.,* 2016). Incorporation of biochar may therefore give higher yield with the same amount of fertilizers, nutrient uptake and availability can also be affected by change in pH as a result of biochar addition (Lehmann, *et al.,* 2013). The total nutrient concentration in biochar can be high, however the proportion of plant available nutrients can vary depending on which kind of feedstock is being used for biochar production. Nutrients as Nitrogen and Calcium, inorganic compounds, are tightly bound and therefore less available to plants, which has been proven from previous studies (Lehmann and Joseph, 2009). Carbon is the major fraction in biochar when produced from plant residues and the average carbon concentration in biochar is found to be 47.6 % (Frossard *et al*., 2016). However, (Gaskin *et al.,* 2018) showed that carbon concentration in biochar produced from poultry manure and pine chips can range between 40-78 %. In general, biochar has a high C/N ratio (mean value of 67) which indicates that immobilization of nitrogen can occur when applied to soil because of the carbon stability it cannot easily be digested by microbes and therefore N mineralization can occur. The surface area can be colonized and small pores act as refugee site for microbes to avoid grazers. The variation in pore size of biochar promotes different habitats and thus microbe diversity (Lehmann and Joseph, 2009).

2.3. Environmental Changes and Farming.

Carbon dioxide (CO_2) is a greenhouse gas which prevents the earth from becoming too cold for life. Since at least the beginning of the industrial revolution, the burning of fossil fuels has released CO_2 in excess of what natural systems are capable of cycling (Chun *et al*., 2014), leaving the atmosphere saturated with CO_2 and causing unprecedented global temperature increases. During photosynthesis, plants take in CO_2, some of the carbon taken in during the process is stored in the plant's stem and leaves. If these plants decompose, some of that carbon is temporarily sequestered in the soil, if they are burned, that carbon is released into the atmosphere as CO_2 and CO. In biochar, the carbon in the plant biomass remains intact and becomes recalcitrant carbon, thus sequestering the carbon for an extended period of time (Deluca *et al***.**, 2016).

2.3.1. Global climate change.

The Global risks report 2016 lists failure of climate change mitigation and adaptation as the number one most impactful global risk. Climate change is also the global risk of second highest concern over the next decade, preceded only be water crises, which is integrally related. For the previous three years, failure of climate change mitigation and adaptation has been in the top five most impactful risks, but has moved to the top spot in 2016 (Giron *et al***.**, 2016).

WEF, (2016) also identifies a cluster of global risks surrounding failure of climate change mitigation and adaptation, including water crises, mass involuntary migration, and food security risks. Nearly 70% of the world's fresh water is used for agriculture, with 40% of world agricultural production requiring irrigation on only 20% of cultivated areas worldwide. (UNESCO, 2016).

Under current agricultural and irrigation practices, competition for water will only increase given the effects of global warming. If every country meets their target

Intended Nationally Determined Contributions plans that they agreed to at the Paris Climate Conference in December 2015, warming is projected to reach well above the 2°C level that scientists have warned implies a high risk of catastrophic climate change (WEF, 2016).

CO_2 is cycled naturally through the atmosphere on both a diurnal and seasonal fluctuation (Karhu *et al.,* 2011). As plants go through their own seasonal cycle, they absorb CO_2 during the spring and summer months, and as their leaves fall and begin to decay through autumn and winter, the global CO_2 levels increase again. Earth's soil is itself an extremely large carbon sinks, containing nearly four times as much carbon as Earth's atmosphere (Steiner *et al.,* 2014). The seasonal CO_2 uptake by plants is eight times the anthropogenic emissions of CO_2 and the entirety of the atmospheric CO_2 is cycled through the biosphere every 14 years (Steiner *et al*, 2014). Vast amounts of CO_2 are cycling annually between plants and the atmosphere. If CO_2 in plants was removed in the form of recalcitrant carbon that would remain in the soil for a longer period than it normally would, carbon would be sequestered. Diverting 1 percent of the annual plant uptake into biochar would mitigate nearly 10 percent of anthropogenic C emissions (Lehmann and Joseph, 2009). This process only works if two conditions are met. First, the rate at which plants are grown has to be equal to or greater than the rate at which they are charred, and second the biochar needs to hold the C in a more stable form than the biomass from which it is made.

2.3.2. Soil erosion.

Soil erosion is both a major agricultural and environmental issue worldwide. (Chun *et al.*, 2014) estimated that soil loss due to erosion worldwide was 26 Billion Mg yr^{-1}. Eleven years later, (Havlin *et al.*, 2015) reported that soil loss due to wind and water erosion was nearly three times higher, at 75 Billion Mg yr^{-1}. Nearly 90% of the world's agricultural land suffers from some sort of erosion, with almost 80% of agricultural land worldwide suffering from moderate to severe erosion. This erosion can reduce the water availability and soil fertility, some corn yields reaching 65% reduction on severely eroded soils in Georgia (Bostrom *et al***.**, 2014).

Around two thirds of global erosion is caused by water, with wind making up another third (Nandawa, 2013). Water erosion has been responsible for the degradation of 1094 million hectares since the middle of the twentieth century (Frossard *et al***.**, 2016). Biochar has been shown to be able to reduce soil loss from water erosion. A laboratory experiment determined that using oak biochar could reduce soil loss by 19.9% against a control, when subjected to 100 mmh^{-1} simulated rainfall. Ding *et al*, (2010) also found that biochar reduced soil detachment in a significant way. If biochar can reduce water erosion on agricultural lands, the rate of land degradation can be decreased, vastly increasing the total possible agricultural yield.

Being a renewable resource and due to its economic and environmental benefits (Fig.2.2), biochar is therefore a promising resource for environmental technology used for water contaminants treatment. Most studies have reported that biochar showed excellent ability to remove contaminants such as heavy metals, organic pollutants and other pollutants from aqueous solutions. Meanwhile, several biochars exhibit comparable or even better adsorption capacity than commercially activated carbon (Adams *et al*., 2007). Specifically, biochar loaded with ammonium, nitrate, and phosphate also proposed to be a slow-release fertilizer to enhance soil fertility, as biochar after adsorption may contain abundance of valuable nutrients (Yuan *et al***.**, 2011).

The available peer-reviewed scientific literatures about the bio- char are mainly concerned about its application in soil, technical, economical, and climate-related aspects (Angst & Sohi 2012). However, very little review article describe the use of biochar for the removal of pollutants in water (Asada *et al.*, 2012) With the increasing interest of scientific research and future engineering applications of biochar for the purification of water and treatment of wastewater, an integrated understanding of biochar's function in aqueous solutions is urgently needed.

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, and in turn the soil biodiversity and soil density increased. Biochar also served as a habitat for extra-radical fungal hyphae that in micropores due to lower competition from saprophytes and therefore served as an inoculum for arbuscular mycorrhizal fungi (Asada *et al.*, 2012). 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 (Chan *et al.*, 2012). However, its recalcitrance and physical nature present significant impediment to the evaluation of long-term stability. The commercially available soil microbes which can be used for inoculation include *Azospirillum* sp., *Azotobacter* sp., *Bacillus thuringiensis*, *B. megaterium*, *Glomus fasciculatum*, *G. mosseae*, *Pseudomonas fluorescens*, *Rhizobium* sp., and *Trichoderma viride*.

2.4. 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. 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 (Deluca *et al***.**, 2016).

The enhancement of water retention after biochar application in soil has been well established, 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 *Vigna radiata* and *Glycine max* plants, with better performances than control or those observed when the strains and biochar are used separately. The use of biochar increased mycorrhizal growth in clover bioassay plants by providing the suitable conditions for colonization of plant roots. (Beesley, 2014) 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. It was found that biochar increased the biological N_2 fixation (BNF) of *Phaseolus vulgaris* mainly due to greater availability of micro- nutrients after application of biochar. (Beesley and Marmiroli, 2011) 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. 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, and larger (>16 μm in diameter) protozoans and nematodes. Biochar can increase the value of non-harvested agricultural products and promote the plant growth. 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. (Ameloot *et al.*, 2013).

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. When biochar was applied to the soil, a higher grain yield of upland rice (*Oryza sativa*) was obtained in northern Los Angeles sites with low Phosphorus availability. 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). However, in some cases, growth was found to be depressed (Beckingham and Ghosh, 2016).

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. 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 fungal inoculations on asparagus tolerance to the soil borne root rot pathogen *Fusarium*, (Beesley and Dickinson, 2015) 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. 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.

2.4.1 Plant root: shoot ratio

The size of a plants roots is an important measure of a plant's ability to obtain resources from the soil, but only insofar as it is used in relation to the size of the rest of the plant (Beesley and Marmiroli, 2011). The measure usually used for this is the root: shoot ratio (RSR) of dry biomass, or less often the root mass fraction; that is, the fraction of total mass represented by the root mass. Functional equilibrium theory and optimal partitioning theory both suggest that plants may be adapted to a specific RSR, but that external factors may cause the plants to shift resource allocation with some degree of plasticity (Chun *et a*l**.**, 2014). A higher RSR may be an indicator of nutrient deficiencies in the soil, specifically a lack of nitrogen, or moisture stress (Hollister, 2011).

Phosphorus has been shown to increase the shoot growth in plants, drastically reducing RSR. Regardless of cause, an otherwise identical plant with larger roots has a better ability to uptake nutrients and moisture (Havlin *et al***.**, 2015).

2.4.2 Effects of biochar on soil quality

An experiment done by (Beesley *et al*., 2015) looked at the effects of biochar, compost and a combination thereof on maize yield and GHG emissions. The biochar was made from willow wood, and the compost was made of green waste, bagasse, chicken manure and compost. Soil available phosphorus (P), CEC and exchangeable calcium were all shown to increase with a biochar amendment (Beesley *et al*., 2016). Bardos *et al*, (2012) examined the effects of different rates of biochar application on multiple abandoned farms. The farms were abandoned at different times and so had different starting compositions. The experiment was over a three-year time period, examining the soil qualities before and after the three years of biochar application. They found that biochar amendments resulted in significant improvements in soil organic carbon, nitrate nitrogen and total soil nitrogen. The biochar did not have significant effect on soil ammonium nitrogen, and reduced soil P, indicating the need for P fertilizer (Chan, 2012). Asada *et al*., (2012) tested biochar made from five feedstocks at five different application rates each. They grew sunflowers in a greenhouse for two months, and tested both soil and plant yield. Biochar was found to reduce the bulk density and increase field capacity of the soils. The biochars were not treated prior to mixing with soil, and biochar application was found to reduce available N in the soil. Bardos *et al*, (2012) replicated golf course root zones to USGA standards and tested the effects of three types of biochar on creeping bentgrass in the USGA root zones. They used a commercially available fast pyrolysis biochar, and biochars made in a gasifier from Paulownia and Frost grape. The root zones were mimicked in long PVC tubes, with different biochar application amounts mixed into the sand part of the root zone. They found that biochar enhanced the nutrient and water holding capacities of the substrates, generally more than treatments which used peat in place of biochar. In all cases, biochar increased nutrient retention, PH, and pore space, in most cases more than peat.

2.4.3 Effects of biochar on plant yield

Ameloot *et al***.**, (2013) found that in a field study growing maize the total biomass and grain yield for both a willow biochar treatment and a compost treatment were greater than the control's, biochar producing a 29% increase and compost 10%. Bostrom *et al*, (2014) found that the sunflower germination was significantly affected by both the biochar feedstock and the rate of application. The biochar also impacted the allocation of biomass within the plants, with biochar samples showing higher leaf allocation and decreased stem allocation. Root allocation was also lower than the control, but not statistically significant. (Steinbess *et al***.**, 2016) examined three biochars from three feedstocks, pine, willow and miscanthus. Based on proximate, and ultimate analysis of the three biochars, the authors decided to use miscanthus biochar for a field test based on its high carbon content and porosity. In their brief article, they did not conduct a statistical analysis, but did conclude that the physiochemical properties are highly dependent on feed stock, and that biochar amendments positively affect plant growth and can increase plant mass. Trying to ascertain the benefits of biochar in sandy soil using sea water as is done in some Middle Eastern countries, Karhu *et al*, (2011) tested biochar application rates in soil irrigated with saline and non-saline water. They found that biochar significantly increased the water use efficiency, a measure of unit yield per unit water, versus a control for water types, 13% for non-saline and 36% for saline water irrigation. Biochar also improved yield with both non- saline and saline irrigation, and under saline irrigation conditions biochar increased yield by 14.0%-43.3%, which was higher than a treatment of just organic matter. There was also evidence that biochar could alleviate stress cause by saline soils and thus increase yield in these situations. After the five-week period (Bardos *et al.*, 2012) found that grass grown in biochar treatments had greater height and root length, whereas less than half had increased dry weight compared to a control. Their conclusion was that some biochars appear to be very useful in sand-based root zones. Several previous investigations focusing on soil and biochar mixtures have shown when biochar is added to soil it can reduce the leaching of PO_4–P NO_3–N and NH_4–N which therefore implies these nutrients are bound to biochar, assuming that no further transformation reactions take place (Beesley *et al.*, 2010). Within these studies the different bio- char production processes and resulting physicochemical properties as well as the nutrient being investigated are key controls on the sorption ability of the biochar. Applying 20 g biochar to an agricultural soil amended with swine manure decreased the leaching of NO_3–N and PO_4–P by 11% and 69% respectively. Soil containing 0.5 wt% bamboo charcoal displayed 15% less NH4–N leaching compared to unamended soil (Ding *et al.*, 2010). The leaching of NH_4–N was also decreased by 94% (Yip *et al.*, 2010) when charcoal was added to a ferralsol and column leached for 37 days (Lehmann *et al*, 2013). Pine biochar produced at 350 °C reduced cumulative NH_3–N losses from soil by 45% when it was amended to soil at 15 and 30 t ha^{-1} (Betts *et al.*, 2013). Pecan shell biochar added at up to 2 wt% dose to a loamy soil reduced PO_4–P leachate concentrations by up to 40% (Novak *et al.*, 2009). Cacao shell in Indonesia, both using the countries respective traditional kilns, was quantified. These biochars were selected as they represent real materials that those in countries with limited technology, but an abundance of waste biomass can produce and in addition are currently in the limited number of previous studies carried out without soil, biochar has been observed to sorb PO_4^{3-}, NH_4^{+} and NO_3^{-}, despite the different charges and properties of these nutrients. Digested sugar beet tailing biochar pyrolysed at 600 °C adsorbed

PO_4^{3-} ions, most likely in binding sites contained in colloidal and nano-sized MgO particles on the biochar surface (Yuan *et al*., 2011). In addition, orange peel biochars pyrolysed between 250 and 700 °C removed between 8% and 83% of phosphate from solution (Chen *et al.*, 2011). NH_4^+ was adsorbed to biochars produced from rice husk (Yip *et al.*, 2012) and a mixture of tree trunks and branches (Jones *et al*, 2012), albeit weakly, as the partitioning coefficients of NH_4^+ between water and biochar were low (Freundlich coefficients of 0.251 mg g^{-1}). NO_3^- has been adsorbed to bamboo charcoal biochar in the concentration range of 0–10 mg L^{-1} (Jansen and Vanbekkum, 2014).

Biochars from sugarcane bagasse, peanut hull, Brazilian pepper wood and bamboo produced at 300, 450 and 600 °C were used to investigate the adsorption of nitrate, ammonium and phosphate from water. The low production temperature biochars released nitrate to the water, while the 450 °C biochars released ammonium and no clear trend was seen for phosphate sorption or release (Yuan *et al.*, 2012). One previous study where essential nutrients were impregnated into oak wood biochar produced at 600 °C demonstrated that the resulting material could act as a slow release fertilizer over periods of greater than 400 h (Khan *et al.*, 2014).

2.5 Spinach Production and its Uses

Spinach is a super cold and popular hardy edible green leaf that can be planted in almost all the regions. It has similitude in its growing conditions with the lettuce but it is more versatile in its nutrition and ability to be taken raw or cooked (Cheng *et al.*, 2016).

As a fast-growing plant that requires just a high humidity area, spinach can be planted by giving a space of 12inches apart in fertile, well-drained soil with a pH of 6.5 to 7.0.

Soil moisture should be checked or consider using a soaker hose to keep moisture levels consistent. Harvest is done with the outermost leaves once leaves are large enough to eat. The spinach seed can be used as dyes or food colorant (Yuan *et al*., 2011) or dried and used for planting the next season, once spinach starts flowering, it makes the leaves, bitter, sour and tasteless making it inedible. Spinach is high in iron, calcium than most cultivated greens, and one of the best sources of vitamins A, B, and C. Spinach is a source of naturally occurring nitrates compound that make the blood vessels to improve blood flow and ease the workload on the heart which invariably controls the blood pressure. Spinach is said to have high potassium content, the potassium content that is usually recommend for people suffering from diabetes and high blood pressure (Beesley *et al*., 2010), the rich Calcium it contains aid in bone development and helps boost the Calcium absorption by the body.

CHAPTER THREE

3.0 METHODOLOGY AND RESEARCH PROCEDURES

3.1 Experimental Procedure

The laboratory experiment was carried out at the Water, Aquaculture and Fisheries Technology (WAFT) laboratory of the Federal University of Technology Minna, Niger State in 2019, while the field work was done at the school farm of FUTMINNA, Gidan Kwano campus. The chapter highlights the apparatus, equipment and methods used to achieve the aim of the project. The ultimate and proximate analysis were carried out to know the percentage of ash content, volatile matter, moisture content, fixed carbon and the elements present in the biochar. The block flow diagram of the experimental procedures can be shown in Figure 3.1.

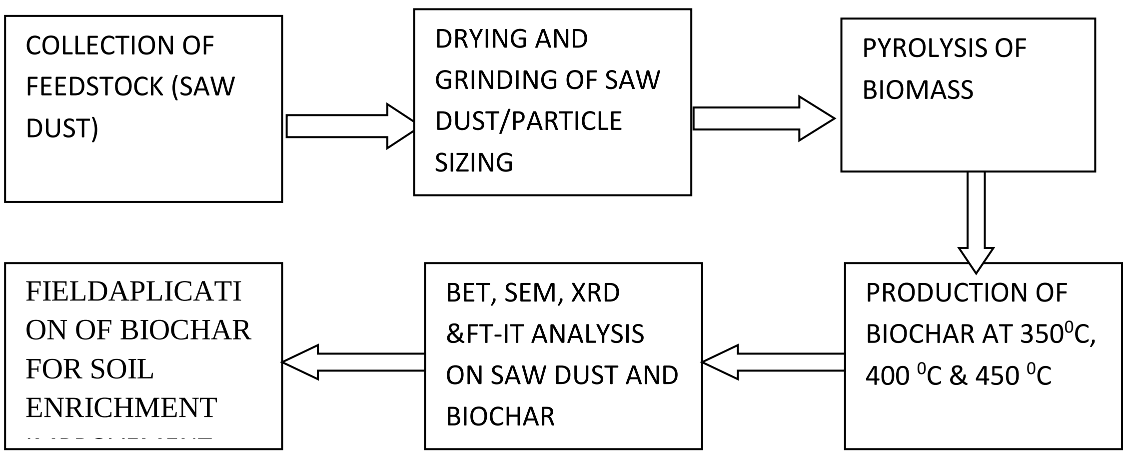

Figure 3.1: Block flow diagram of experimental procedure

3.2 Laboratory Experiment

3.2.1 Equipment and apparatus used

Equipment

The list of laboratory equipment used for this research work are shown in table 3.1

Table 3.1: List of Equipment

S/N	Equipment/Materials	Source
1.	Heating Furnace (Lenox, 2003 Model)	Cereal Research Institute, Badegi
2.	Oven (Amana Bosch, 2006)	WAFT Laboratory FUTMINNA
3.	Gas Cylinder (Setro, 2016 Model)	STEP B Laboratory FUTMINNA
4.	Stop watch (Robic, 2018 Model)	WAFT Laboratory FUTMINNA
5.	Crucibles (Pyromatics, 2017 Model)	WAFT Laboratory FUTMINNA
6.	Weighing Balance (Amalex, 2013 Model)	WAFT Laboratory FUTMINNA
7.	Saw Dust	Sawmill, Maitumbi, Minna
8.	SA3100 Surface analyser (Anton Paar, 2018)	STEP B Laboratory FUMINNA
9.	Sieves (Genuine Hardox, 2008 Model)	Chemical Engineering Lab, FUTMINNA

3.2.2 Equipment and materials for ultimate analysis

Digestion unit, Analytical Scale, Fumes hood, Glass wares

3.2.3 Chemicals and solutions

Sulphuric Acid, Distilled water, Copper sulphate (catalyst)

3.2.4 Material preparation

Saw dust (Pine wood) was selected for this experiment and it was obtained from the saw mill at Maitumbi, Minna, Niger State. The saw dust was kept under the sun for three days. The sample was further sieved with 2.8 mm, 2.00 mm, 1.40 mm and 1.00 mm sieve. The sample was manually placed in the sieve to ensure uniformity. The process was then repeated severally to ensure the particles attained the desired sizes. The sample was then taken to STEP B Laboratory for pyrolysis.

3.2.5 Particle size distribution

The particle size of the saw dust was determined by using a stack arranged with different aperture ranging from 2.8 mm – 1.0 mm. The sieve with 1.40 mm aperture retained the larger quantity of the saw dust.

3.2.6 Pyrolysis of saw dust

The saw dust was re-dried in an oven at a temperature of 80 ^{o}C for an hour. A cylinder containing nitrogen gas was connected to the heating furnace in order to keep the system un-reactive and stable. The heating furnace was heated at three (3) different temperatures (300 ^{o}C, 350 ^{o}C and 400 ^{o}C) with different holding time (30mins, 60mins and 90mins) to help in ascertaining the temperature and holding time for biochar with highest nitrogen. At the end of the pyrolysis process the biochar was brought out and allowed to cool for about 30 minutes.

3.2.7 Proximate analysis

The proximate analysis of the biomass is essential to determine the chemical composition of the biomass and to provide their various combustion characteristics. The proximate analysis is divided into four constituents namely: Moisture content, as content (inorganic matter left after combustion), volatile matter (the gases emitted during the thermal decomposition of the biomass in an inert atmosphere) and fixed carbon (calculated by the difference).

3.2.7.1 Moisture content analysis

An empty crucible was weighed and put in an oven for 30 minutes at 100 ^{o}C to eliminate any trace of moisture, the crucible was put in a desicator to cool and then reweighed, and the weight was noted. 1 g of the sample was weighed out into the crucible and then weighed. The sample was the placed in the oven (Amana Bosch, 2006 model) set at 105 ^{o}C and left for 1hour. The crucible and its content were then removed and placed in a desicator to cool down and then reweighed.

$$Moisture\ content\ (\%) = (W3 - W1) \div (W2 - W1) \times 100\% \qquad Eqn\ 3.1$$

Where W1= Weight of clean dry crucible (g)

W2= Weight of crucible + Wet Sample (g)

W3= Weight of crucible + dry sample

3.2.7.2 Ash content analysis

1.0g of the dried sample of biochar was weighed and heated in a furnace at 500 ^{o}C for 30minurtes, heating was carried out in a furnace and left in a desicator to cool down to room temperature and weighed. This weight was recorded as the final weight of ash by using the following equation in grams (g).

Ash content (%) = $weight\ of\ ash/initial\ weight\ of\ dry\ sample\ \times 100 \qquad Eqn\ 3.2$

3.2.7.3 Volatile content analysis

The volatile matter of the biochar was determined using the Meynell Method (Lehman and Joseph, 2009). 1.0 g of the residual dry sample each from moisture content determination was placed (spread evenly) on an empty crucible, after weighing the empty crucible and it was covered and placed in a furnace heated at 700 ^oC for 15minutes to drive off the volatiles. The resulting samples was further heated at 600 ^oC for 10 minutes, placed in the desicator and allowed tom cool and then calculated using the following equation below:

$volatile\ matter(\%) =$

$loss\ in\ weight\ due\ to\ removal\ of\ volatile\ matter / weight\ of\ sample\ taken \times 100$

Eqn 3.3

3.2.7.4 Fixed carbon determination

The fixed carbon analysis gives a measure of what is left out of the biomass when moisture, volatiles and ash have been removed. The fixed carbon of the biochar was calculated using the following equation: $fixed\ carbon(\%) = 100 - (moisture\ content + volatile\ matter + ash\ content)$ $Eqn\ 3.4$

3.2.8 Ultimate analysis

Elemental components of the biochar were determined by an elemental analyser. 1.0 g of biochar was weighed and heated at a temperature of 125 ^oC in an oxygen atmosphere, so the carbon was converted to CO_2, sulphur into sulphur IV oxide gas and the Nitrogen into nitrogen gas. The first three compounds were detected quantitatively by an IR detector, while N_2 was determined by a thermal conductivity detector.

3.2.8.1 Carbon and hydrogen contents

Big-Pregle method was used to determine the carbon and hydrogen content (Bostrom *et al.,* 2014). To determine the carbon and hydrogen content: 1 g of the biochar was placed in quartz tube and burnt off through the absorbent magnesium percolate to absorb water and sodium hydroxide to absorb carbon dioxide. The amount of water and carbon dioxide were determined from the difference between the weight before and after absorption of water. The hydrogen and carbon percentage (%) were calculated as: $\%C = (0.2727)/g \times 100 \quad Eqn\ 3.5$

3.3. Characterization of Saw Dust and Biochar

3.3.1 Brunauer-emmett-teller (BET) analysis

The determination of the adsorption capacity of the biochar produced was necessary and this was carried out using the BET analysis to determine surface area and pore volume of the produced biochar. The biochar sample was dried at 110 ^{o}C for 45 minutes and out-gassed at 300 ^{o}C under vacuum for two hours prior to measurement. The sample was measured on a Beckman Coulter SA3100 surface area analyser (STEP B FUTMINNA) at the temperature of liquid nitrogen (196 ^{o}C).

3.3.2 Fourier transform infrared

The FT-IR generates the graph in the form of absorbance spectra which shows the unique bonds (organic polymeric materials) and the molecular structure of the sample material. This adsorption spectrum will have peaks representing functional groups. These absorbance peaks indicates functional groups (alkanes, ketones, acid chlorides). Different types of bonds and different functional groups absorb infrared radiation of different wavelength.

3.3.3 SEM analysis

The SEM analysis is a test process that scans a sample with an electron beam to produce a magnified image for analysis and it's used very effectively for microanalysis and failure analysis of solid inorganic material. The signals generated during the SEM analysis produce a two dimensional image and reveal information about the biochar including the external morphology (texture), chemical composition when used with the EDS feature and orientation of materials making up the sample. The EDS component of the system is applied in conjunction with SEM analysis to determine elements in or on the surface of the biochar for qualitative information.

3.3.4 Cation exchange capacity analysis (CEC)

Cation exchange capacity has a significant influence on the physical and chemical behaviour of soil and this is measured by displacing all the bound cations with a concentrated solution of another cation and then measuring either the displaced cations or the amount of cation that is retained. 2.0 g of biochar was placed in a 250ml flask and 100ml of ammonium solution (pH =7) was added, mixed thoroughly and allowed to stand overnight. The solution was filtered with light suction using a funnel and it was re-filtered with an additional ammonium solution (pH = 7), Ca^{2+}, Na^{+}, Mg^{2+}, K^{+} were checked for using ammonium chloride (NH_4Cl) and ammonium hydroxide (NH_4OH).

3.3.5 X-ray diffraction (XRD) analysis

X-ray diffraction analysis carried out was important in the determination of structure of the biomass carbon used in this research. 1.0 g sample of the biochar was put into a circular disc then placed on spring cover which was clamped on a bigger cylindrical disc. The mechanism was such that once the sample was clamped to the bigger disc it holds the sample firmly in place and ready for x-ray diffraction measurement. The sample was placed in the x-ray machine (Siemens D500 X-ray Diffraction system) and the computer linked to the X-ray machine was readjusted for fresh reading. The X-ray machine shuttle was switched on. The computer reading was readjusted to 0^{o} to 80^{o}.

3.4 Field Experimental Design of Biochar Application

3.4.1 Study location

The location considered for this research study was the school farm of the Federal University of Technology Minna, Niger State, Gidan Kwano Campus (09^0 39N and 06^0 28E) with altitude 281.1m above the sea level. Field experiment was done in the year 2019.

3.4.2 Source of planting materials

The seeds and fertilizer used for this research study were bought at the Chanchaga Market, Minna, Niger State in October 2019.

3.4.3 Nursery

Four (4) small bowls of 50ml in size were filled with loamy soil and properly watered to make the soil moist, the spinach seeds were evenly broadcasted in these bowls and watered again, the bowls were kept outdoor to enable sunlight penetrate through, the seedlings were watered every morning. Watering was reduced a day before transplanting to give seedlings chance to get used to strong sunshine (hardening). The seedlings were transplanted to the field after 2 weeks, holes were dug 10 cm apart and the seedlings were planted.

3.4.4 Land preparation

The measurement of the land used for planting was 3 m^2 by 3 m^2. The experimental field was cleared manually with a cutlass after which the land was ploughed with a hoe in beds of 10cm apart. Broadcasting method of application of biochar was incorporated for this research study. 20 g of biochar was use on each bed, biochar was sprayed over the land and tilled with soil.

The field experimental design is shown in the figure below:

Treatments

Biochar application

Treatment 1 ($T_{1)}$ = the control portion (portion of land without Biochar and fertilizer)

Treatment 2 (T_2) = the portion with Biochar only (20 g per bed)

Treatment 3 ($T_{3)}$ = the portion with only fertilizer (1:1:1)

Treatment 4 ($T_{4)}$ = the combination of Biochar and Fertilizer (20 g of biochar +10 g fertilizer)

3.4.5 Planting

The seedlings were transplanted after 2 weeks by taking the bowls of spinach bed to the cleared field, digging holes of 5-10 cm on the field and transplanting to each treatment on a 5 cm spacing.

3.4.6 Irrigation

The spinach bed was manually watered six days a week using a sprinkler of 100 ml for the entire bed.

3.4.7 Weeding

Weeding was carried out manually using hoe at every two (2) weeks after transplanting (WAT)

3.4.8 Fertilizer application

Fertilizer was manually applied using granular NPK of 10-10-10 by using a cup of 5ml on bed with 5cm spacing.

3.4.9 Insect Pest Control

The insect pest control was done using a float row net to cover the bed.

3.5 Soil Analysis

Top soil samples, 10cm in depth were collected from the field before planting and at harvest. For each of the collected samples, soil properties including soil P_H soil organic matter, available phosphorus, and nitrogen as nitrate and cation exchange capacity were determined at the Soil Science laboratory, FUTMINNA.

3.6 How Parameters were Calculated

1. Days to germination**:** This was determined by closely observing how the spinach sprung up in the nursery bed
2. Percentage Germination: The percentage germination was arrived at by daily observation at the nursery bed.
3. Plant Height: The plant height was measured with a tape rule by holding the pole closed to the stem of the spinach and measured from the ground level or the collar point to the leaf base of the highest expanded leaf.

4. Stem Girth: The stem girth was measured after harvesting using a meter rule and a Vernier calliper respectively, significant difference was observed for the stem girth in all the four treatments.
5. Harvesting: This is the period whereby the spinach is ripe and due to be harvested and this mostly 3-4 weeks but the harvesting varied because of the treatments applied. The harvesting was done by uprooting the entire spinach from each treatment manually using hands
6. Total fresh mass of spinach: This was measured by weighing the harvested spinach from all the four treatments on a digital weighing scale (Amalex, 2013 model). It is calculated in grams.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

The results of the analysis carried out on the raw material, the biochar and the outcome from the field trial application of the biochar produced. Some of the results include the proximate and ultimate analysis of the biochar carried out at the WAFT laboratory FUTMINNA, the BET carried out at the STEP B laboratory FUTMINNA, the XRD (x-ray diffraction pattern), the CEC (cation Exchange Capacity) and the SEM analysis.

4.2 Proximate and Ultimate Analysis

4.2.1 Proximate analysis

The proximate analysis of the biochar and saw dust were carried out to effectively know the percentage of moisture content, ash content, volatile matter and fixed carbon. The results of this analysis is shown in Table 4.1.

Table 4.1. Proximate Analysis of Biochar and Saw dust

Sample	Moisture content %	Ash Content %	Volatile Matter %	Fixed Carbon %
Saw Dust	11.65	2.30	53.50	32.55
Biochar	4.32	26.12	35.22	34.34

The moisture content, ash content, volatile matter, fixed carbon of the biochar was obtained as follows 4.32%, 26.12%, 35.22%, 34.34% respectively compared to saw dust of 11.65%, 2.30%, 53.50% 32.55%, the differences in the percentages were due to the different biomass material, drying temperature and procedures used for the experiment, the drying temperature used differs from each biomass material. The low moisture content of the biochar is advantageous to the soil because it would help in water retention capacity which would invariably boost the microbial activities in the soil and this is very helpful to spinach growth. The ash content is a merit in increasing the pH of soil, ash is known to contain high level of calcium which helps in increasing pH of a solution and spinach growth has been studied to thrive better on soil pH that is high. The fixed carbon in biochar signifies the amount of carbon left after the saw dust has been pyrolysed, this would also help to add nutrients to the soil and sequester the carbon in the soil to prevent greenhouse effect.

4.2.2 Ultimate analysis at different temperatures

The ultimate analysis of the biochar at different temperatures were investigated to know the optimum temperature at which a better and more stable biochar could be produced. The results of this analysis are tabulated as shown in Table 4.3 below.

Table 4.2. Ultimate Analysis of Biochar at Different Temperatures

Sample	Carbon(C)%	Nitrogen(N)%	Hydrogen(H)%	Oxygen(O)%	CEC(c/mol/kg
Biochar-300 °C	66.73	2.85	2.97	13.62	15.30

Biochar-350 ^{o}C	72.45	3.60	2.66	13.02	13.45
Biochar-400 ^{o}C	81.46	1.69	1.94	10.32	13.10

From the table 4.2 it could be inferred that the biochar produced at a temperature of 350^{0}C had a good carbon content which implies that carbonizaion degree is enhanced by increasing temperature. The ultimate analysis was carried out on both the saw dust and the biochar and there was a significant difference in the composition of both materials. The carbon, hydrogen, oxygen, nitrogen and sulphur of the saw dust were 51.40%, 6.70%, 36.86%, 1.41% respectively compared with the values obtained from the biochar, 72.45%, 2.66%, 13.02%, and 3.60%. The nitrogen composition is very essential to boosting soil fertility because it is needed mainly by plants and this nitrogen can be released in a more sustainable way into the soil when biochar is applied. The reduction in hydrogen and oxygen content was due to the weaker bonds inside the biochar matrix. There was a high percentage of nitrogen in biochar produced at 350^{o}C which indicates that wood derived biochar had good potential for net Nitrogen immobilization in the soil. These results generally showed that at elevated temperature more recalcitrant carbon structure was formed inside the biochar matrix, from the ultimate analysis carried out, the Biochar produced at 350^{o}C was more suitable to be used for soil enrichment with its high carbon, nitrogen and cation exchange capacity content. The CEC is a measure of the ability of materials to adsorb cations such as Ca^{2+}, Mg^{2+} or k^{+}. However, (Armitage & Gobas, 2015) showed that the CEC of biochar is greatly dependent on the pyrolysis temperature and properties of the raw material. The greater CEC of the Biochar was due to the higher charge density per unit surface area, the formation of carboxyl groups, a more porous structure or a combined result of the three factor. The higher CEC value of biochar indicates its stronger ability to hold essential nutrients as well as greater its resistance against the acidification of soil. The biochar produced at 350°C had a CEC of 13.45 c/mol/kg which would be more beneficial in soil amendment/enrichment in agronomy. The biochar used in this experiment had a very high nutrient composition compared to the feedstock (saw dust), these properties made the biochar of very essential value in agronomy and can thus be used as soil amendments especially in combination with organic and inorganic fertilizers.

4.2.3 Ultimate analysis of biochar and saw dust at 350 °C

The Ultimate Analysis of Biochar at 350 °C is tabulated in table 4.3. This analysis was carried out to know the percentage level of nitrogen, oxygen, carbon, hydrogen and sulphur present in the biochar at 350 °C.

Table 4.3. Ultimate Analysis of Biochar at 350 °C

Sample (%)	Carbon (C) (%)	Hydrogen (H) (%)	Oxygen (O) (%)	Nitrogen (N) (%)	Sulphur (S) (%)
Saw dust	51.40	6.70	36.86	1.41	0.00
Biochar	72.45	2.66	13.02	3.60	0.00

From the table 4.3, the ultimate analysis of biochar at 350 °C indicates the carbon, hydrogen, oxygen, nitrogen and sulphur of the saw dust are 51.40%, 6.70%, 36.86%, 1.41% respectively compared with the values obtained from the biochar, 72.45%, 2.66%, 13.02%, 3.60%, we could infer that the carbon in the biochar is higher than that of the saw dust due to the fact that it had been subjected to immense heat, the nitrogen composition of the biochar was found to be higher than that of the saw dust because some of the nitrogen gas were captured by the biochar during pyrolysis which resulted in about 200% increment in the nitrogen content of the biochar. The nitrogen composition is very essential to boosting soil fertility because it is needed mainly by plants and this nitrogen can be released in a more sustainable way into the soil when biochar is applied.

4.3 BET Analysis

The BET analysis determines the surface area of a material, this analysis was done on both the saw dust and the Biochar. The table 4.4 shows the results of the BET analysis carried out.

Table 4.4. BET Analysis of Biochar

Sample	Surface area (m^2/kg)	Pore Volume (cc/g)	Pore Size (n/m)
Raw saw dust	1.384	0.879	1.787
Biochar	591.0	0.1747	6.077

The BET Analysis of biochar was done to know the surface area, pore volume and pore size of both the biochar and the saw dust. The BET analysis for the more suitable biochar (Biochar at 350 ^{o}C) and raw saw dust were carried out to investigate the surface area properties of both materials to see the changes. It was observed that the surface area of biochar was increased massively compared to the surface area of raw saw dust (from 1.384 m^2/kg to 591.0 m^2/kg), this occurred as a result of the carbonization at that temperature, when biomass is subjected to immense heat, the hemicellulose and lignin are degraded making the biochar to have more pores which results to higher surface area. Greater surface area is very essential in soil enrichment because it helps in improving soil properties and increases soil retention capacity to a greater extent.

4.4 Fourier Transform Infrared Transform (FT-IR)

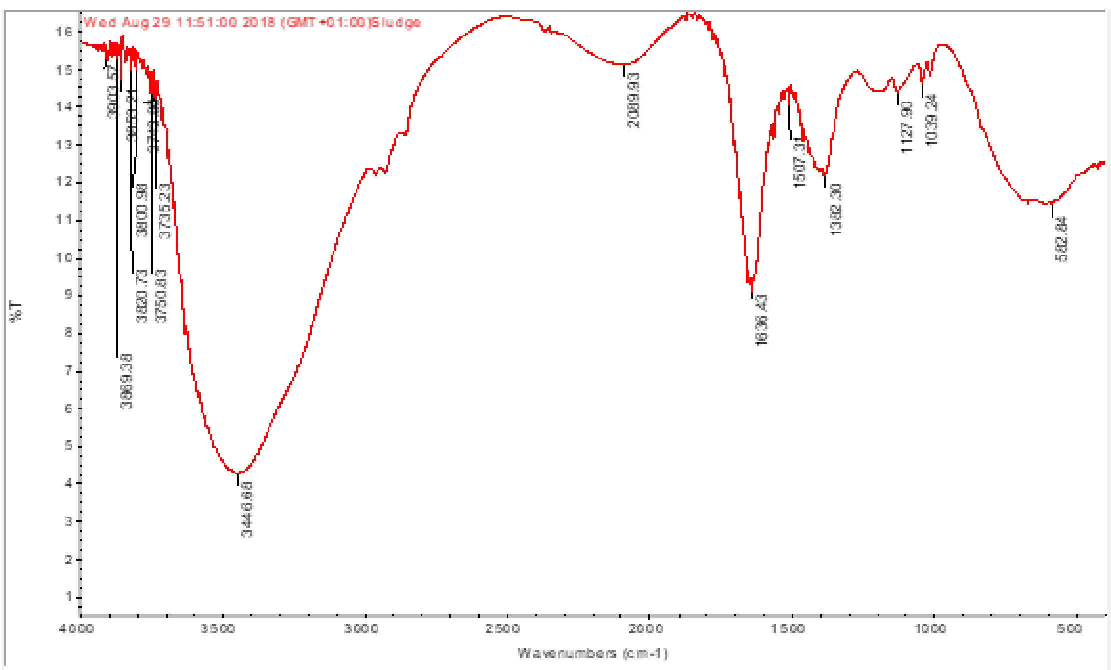

Figure 4.1. Fourier Transform Infrared of Saw dust

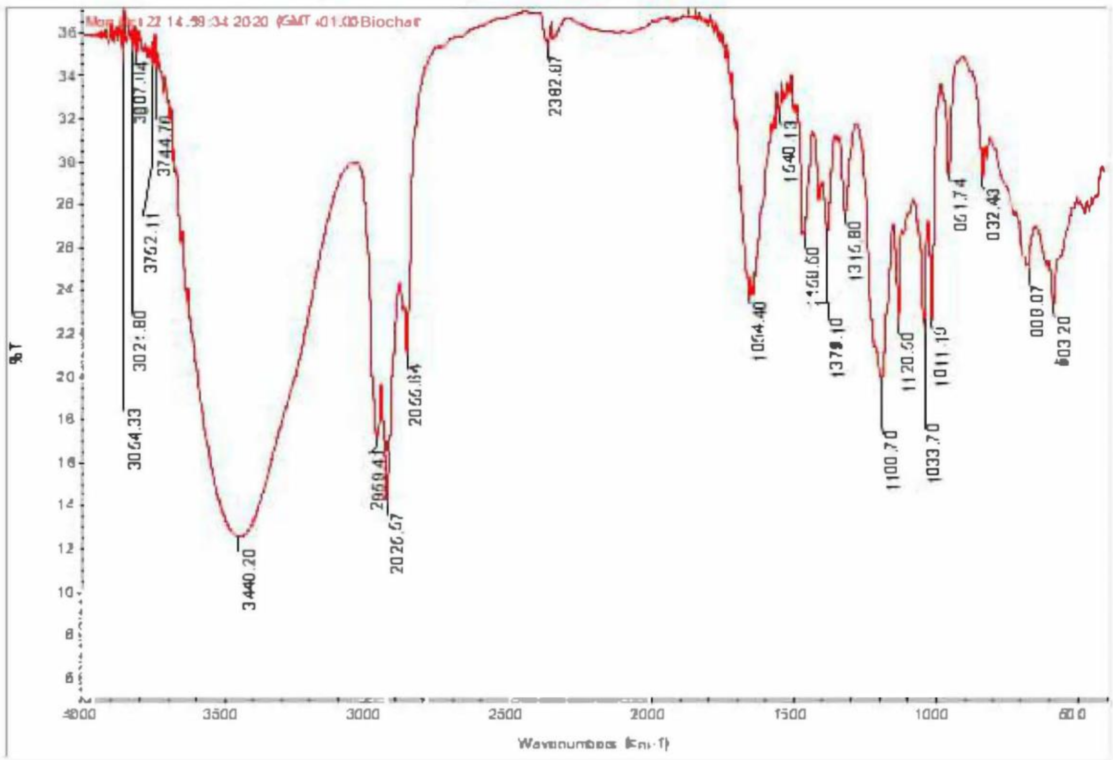

Figure 4.2. Fourier Transform Infrared of Biochar

The FT-IR spectra revealed functional groups in all the samples investigated. These functional groups were revealed in the scan range of 4000–500 cm^{-1}. The characteristic peak in Figure 4.1 at 3464.68 cm^{-1} belongs to the O-H group whereas 1636.43 cm^{-1} represents Carboxylic group, while 2426.52 cm^{-1} shows the presence of C-H stretching out. The characteristic peak in Figure 4.2, 3440.20 cm^{-1} corresponds to C-H deformation of Cycloalkanes. The peak at 1342.61 corresponds to the C-H deformation of hemicellulose, the peak at 1054.40 cm^{-1} corresponds to the C-H out-of-plane deformation of cellulose compounds. Similarly, the FTIR spectrum for the biochar showed several peaks. The peaks at 3440.20 cm^{-1}, 2026.57 cm^{-1}, 3054.33 cm^{-1}, 2055.84 cm^{-1} reveals the C-H bonding and affirms the presence of carbon and hydrogen compounds in the biochar.

4.4 SEM Analysis

The saw dust and biochar were subjected to scanning electron microscope (SEM) to have a clear understanding of the structure and size distribution of the biochar, the SEM image was taken under a magnification of Fv400 (x5000), the figure 4.3 shows the structure of the Saw dust before it was pyrolysed.

Figure 4.3. SEM Analysis of Saw Dust

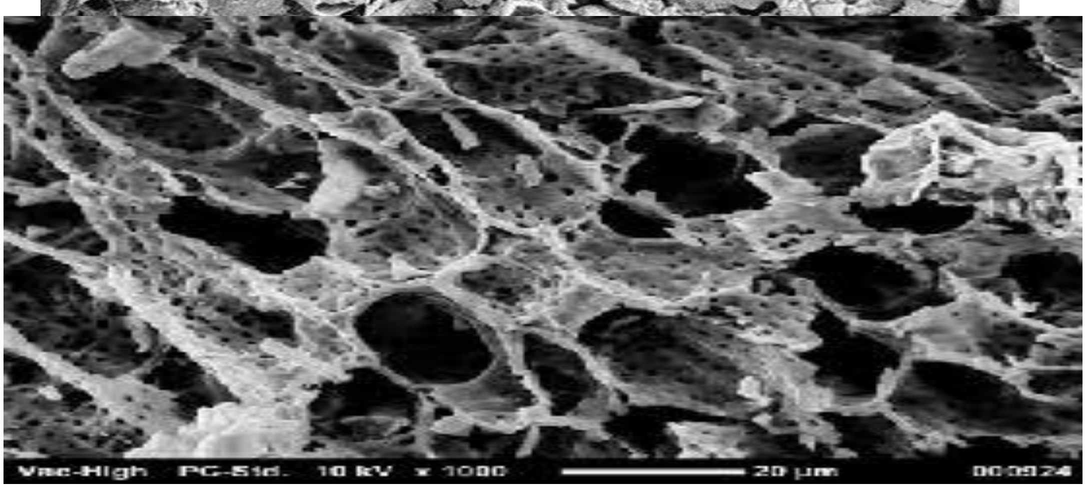

Figure 4.4. SEM Analysis of Biochar

The morphology of the saw dust showed bulging spheres indicating the larger surface area in the saw dust before subjecting it to pyrolysis. The SEM analysis of the biochar smaller multiple spherical loosed shapes indicating larger pores and lower surface area as compared with the sawdust after it was subjected to intense heat, which indicates that the size distribution (pore size) was largely dependent on the temperature of pyrolysis. The images also revealed presence of porous structure on the surfaces but some pores were filled by volatile matter. The presence of volatiles in the pore structure of biochar has been reported in rice husk and willwood saw dust biochar (Jaeztold and Schimdt, 2016a).

4.5. X-Ray Diffraction Pattern (XRD)

Figure 4.5 and 4.6 shows the X-ray diffraction pattern for the saw dust and the pyrolysed saw dust (biochar).

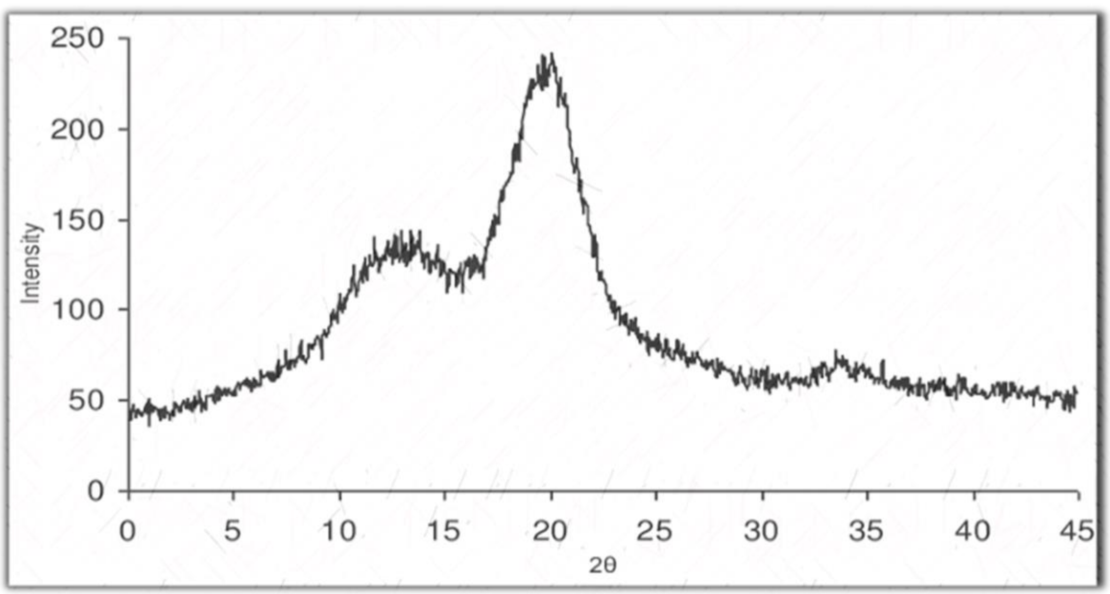

Figure 4.5. XRD of saw dust (pine wood)

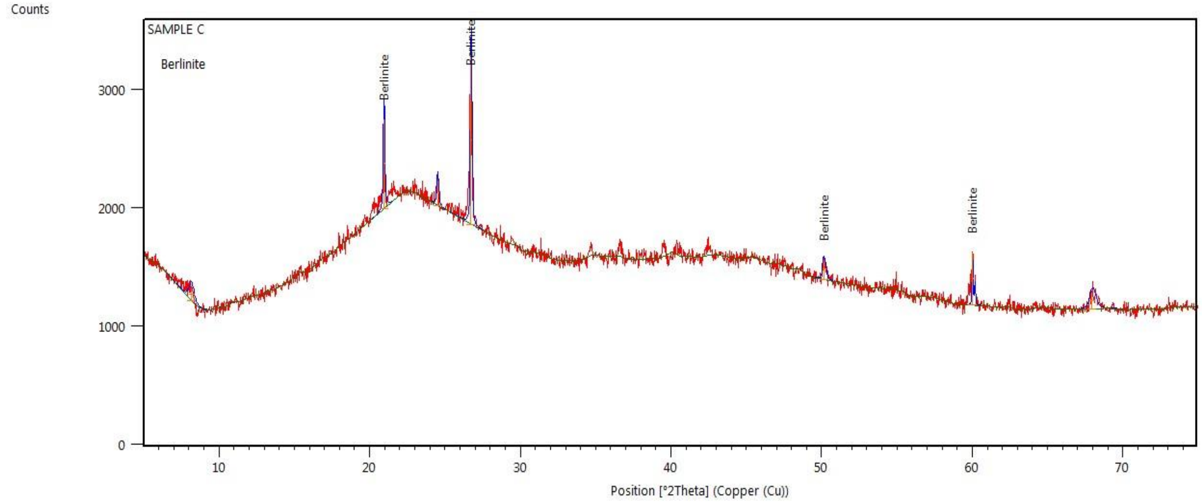

Figure 4.6. XRD Pattern of Biochar

The absence of peaks in the X-ray diffraction pattern of the saw dust from figure 4.5 shows that cellulose, hemicellulose and lignin are present in the saw dust. From the figure 4.6, the highest peak is at an angle of 20.10^0 and 26.12^0 (2θ-axis), the presence of these two sharp peaks were attributed to degradation that occurred during pyrolysis. However, the peak at 2θ-axis indicated berlinite and calcite. The absence of multiple sharp peaks denoted the amorphous structure of the biochar sample (Nandwa, 2011).

4.6 Soil Analysis before and after Experiment

The soil analysis of the portion of land used for this experiment was carried out, the analysis was carried out before the planting was done and after the harvesting was carried out and are presented in table 4.5 and 4.6.

Table 4.5. Soil Analysis before Experiment (10g per weight)

Treatments	Soil organic	Phosphorus (P) mg	Potassium (k) mg	Magnesium (Mg) mg	Calcium (Ca) mg	Nitrogen (N) mg	pH

	matter%						
Treatment1	2.9	16	202	340	1950	16	5.6
Treatment2	2.6	21	222	431	1721	33	5.3
Treatment3	3.1	26	180	440	2471	27	5.6
Treatment4	3.4	20	195	404	1982	38	6.0

The soil analysis was done on the four treatments where the spinach was planted, it could be deduced that the soil organic matter, phosphorus, potassium, magnesium, calcium, nitrate and pH of the soil all varied because leaching might have occurred before the application of biochar leaving some portion of the land unfertile or weak in nutrients.

Table 4.6. Soil Analysis after experiment (10 g per weight)

Treatments	Soil organic matter%	Phosphorus (P) mg	Potassium (K) mg	Magnesium (Mg) mg	Calcium (Ca) mg	Nitrogen (N) mg	pH
Treatment1	3.5	28	118	313	1802	14	5.1
Treatment2	3.2	25	201	442	1921	41	5.9
Treatment3	3.9	33	174	406	2411	18	5.2
Treatment4	5.5	42	223	396	2114	39	6.4

The soil analysis was carried out after the harvesting was done and there was a very clear distinction in the way the nutrients varied as against the analysis carried out before planting was done. The treatment with the combination of biochar and NPK fertilizer prove to be more effective in soil enrichment than the treatments with biochar alone and fertilizer alone, this is because biochar aided or served as a good support to keep fertilizer in its matrix because of its pore size not only as a soil improver. From the table 4.6 above, it could also be inferred that the treatment with biochar alone also had a very positive impact on the soil as it improved the soil pH from 5.3 to 5.9, the nitrogen also increased from 33mg to 41mg which occurred as a result of the level of nitrogen in the biochar applied to the soil, the calcium level in the soil before application of biochar was 172mg but there was a sharp increase of calcium level after harvesting was done (1921mg), which indicates a positive outcome of the application of biochar to enrich soil.

Table 4.7. Effect of Portion (bed) with Biochar and Fertilizer on days of germination

Treatment	Days to germination
1	175.2hours

2	156hours
3	144hours
4	108hours

From the table 4.7, the combination of biochar and fertilizer had a great impact on the days of germination of the spinach and this could be ascribed to the fact that the biochar acted as a support mechanism to the fertilizer and also provided an enabling environment for microbials which aided in faster germination in treatment with biochar and fertilizer combination.

Table 4.8. Effect of Portion (bed) with Biochar and Fertilizer on percentage germination

Treatment	3days	7days	10days
1	25%	40%	70%
2	25%	45%	75%
3	35%	55%	85%
4	40%	60%	90%

Treatment

1 = Control

2 = Biochar

3 = Fertilizer

4 = Biochar + Fertilizer

From table 4.8, the treatment with the biochar and fertilizer combination had higher percentage germination from the third day after planting was done as compared with the treatment with fertilizer and the treatment with only biochar, the reason for mass germination in treatment with biochar and fertilizer could be due to the enriching nutrients like calcium, nitrogen, phosphorus in the biochar combined with the fertilizer applied on this treatment.

Table 4.9. Effect of Portion (bed) with Biochar and Fertilizer on Plant height (cm)

Treatment	2WAT	4WAT	6WAT
1	6.32	28.21	41.10
2	8.48	31.64	42.90
3	9.02	33.54	42.46
4	11.27	35.52	43.90

From table 4.9, the plant height of the spinach bed was taken 2weeks interval after transplanting to the experimental field, the treatment with biochar and fertilizer prove to have the highest plant height as compared to other treatments and it could be deduced that the rich calcium and nitrogen content in the biochar acted positively in increasing the plant height of this treatment. The combination of biochar and fertilizer had a significant impact on the plant growth because of the enriched soil by the biochar.

Table 4.10. Effect of Portion (bed) with Biochar and Fertilizer on Stem girth (cm)

Treatment	4WAT	6WAT
1	1.98	4.19
2	2.16	4.87
3	2.28	4.69
4	2.86	5.72

The table 4.10, shows the effect of portion with biochar and fertilizer on stem girth. The stem girth of the spinach from all the treatments were calculated using a tape rule after 4 weeks and 6 weeks of transplanting. The stem girth of the treatment with biochar and fertilizer had a higher a value as compared with other treatments which was as a result of the increased CEC in the soil and a balanced soil pH from the combination of the biochar and fertilizer. This combination has proven to be very effective in increasing the stem girth of spinach.

Table 4.11. Effect of Portion with Biochar and Fertilizer on number of leaves

Treatment	2WAS	4WAS	6WAS
1	10	19	31
2	16	22	35

3	12	26	37
4	14	31	41

From table 4.11, the number of leaves from the four treatments were put into consideration to evaluate the yield of spinach, the number of leaves were counted on an interval of 2 weeks after sowing (WAS) had taken place. The tagged stem on each treatment had their leaves counted and treatment with biochar and fertilizer had the highest count compared with other treatments which was due to the boosted soil fertility by the biochar. The biochar had rich nitrogen content needed for spinach growth which was a key factor in the high number of leaves in treatment 4.

Table 4.12. Effect of Portion with Biochar and Fertilizer on harvest

Treatment	Harvesting
1	38days
2	36days
3	37days

4	34days	Treatment

1 = Control

2 = Biochar

3 = Fertilizer

4 = Biochar + Fertilizer

The table 4.12, shows the harvesting period of the spinach. The control treatment was harvested after 38days of planting because the maturity was slow due to lesser nutrient in the soil to provide faster growth for the spinach. The treatment with biochar and fertilizer were harvested after 34 days because the maturity stage for harvest was attained due to increased cation exchange capacity (CEC) in the soil and conducive environment for microbes to function in the soil which resulted in quicker maturity of the spinach. The addition of biochar and fertilizer can be inferred to be the best combination for spinach growth.

Table 4.13. Effect of Portion with Biochar and Fertilizer on mass of Spinach (Kg)

Treatment	Total mass (kg) of Spper bed

1	3.20
2	3.26
3	3.40
4	3.81

The table 4.13, shows the mass of spinach per plot. The mass of the harvested spinach was weighed to know the treatment with the highest mass (kg). The treatment with biochar and fertilizer had thicker stem buds, wider and bigger leaves than the rest treatment which contributed to the larger weight. The increased weight was greatly as a result of enriched soil fertility resulting to better spinach yield.

Plate I: Spinach from treatment with biochar and fertilizer. **Plate II:** Spinach from treatment with biochar

Plate III: Control bed

5.0 CHAPTER FIVE

5.1 CONCLUSION AND RECOMMENDATIONS

In this research study, sawdust was successfully pyrolysed to produce biochar at an operating temperature of 350 ^{o}C with holding time of 60 minutes. Biochar produced at this temperature was discovered to have a high nitrogen content and a good cation exchange capacity beneficial for soil enrichment.

The characterized biochar indicated a large surface area and pore size making it a suitable habitat for micro-organisms to inhabit and boost spinach yield. The SEM analysis clearly showed the difference in pore size in both sawdust and biochar, the higher the pore size the better the biochar. The cation exchange capacity of the biochar indicated a high amount of cation exchange capacity which would invariably help in increasing cation solutions in the soil.

The soil analysis of the field done before and after the experiment showed a good rise in nitrogen, calcium, magnesium, phosphorus and soil pH which was largely due to the application of biochar to enrich the soil.

Deductively, the treatment with biochar and fertilizer combination has proven to have the best capability in boosting soil fertility and increasing the yield of spinach planted, the pant height, stem girth, number of leaves, mass of spinach harvested all showed that the combination of biochar and fertilizer is best suited for farming practice.

5.2 Recommendations

Further studies should be done on the nutrient properties of spinach planted using biochar and fertilizer as soil enricher.

An indepth study should be carried out on the use of biochar in the amendment of contaminated soil in the oil spillage region.

A detailed study of the life span of biochar in the soil should be carried out and its long-term effect on degraded soil.

The use of biochar in waste management and its effect on the environment should be embarked upon.

5.3 Contribution to Knowledge

The research study carried out on the enrichment of soil using biochar and testing the effect on the yield of spinach prove that the nutrient contents of the soil such as pH and nitrogen content increased by 6.4% in the treatment with biochar as compared to the control treatment.

The application of biochar for soil enrichment aided in increasing the yield of spinach by 3.32% when compared with control treatment.

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