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THE APPLICATION OF BIOCHAR PRODUCED FROM COCONUT SHELL IN SOIL AMENDMENT

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ABSTRACT

Nigeria is considered to be an agrarian State which generates tones of organic waste with a promising potential for reuse, but this needs to be more utilized for other purposes of high economic value. In this study, biochar was produced from coconut shells using pyrolysis in a muffle furnace at 300 ℃ and hydrothermal carbonization of the biomass at 200 ℃ for two hours. The produced biochar was pulverized and characterized for pH, particle size distribution, proximate composition, FTIR, TGA, and SEM to identify pore size. The FTIR characterization data of the biochar produced twelve functional groups appearing within the range of 1500-4000 $cm^{-1,}$ predominantly the N-H functional groups, which authenticates the alkaline nature of biochar. The proximate analysis showed ash content of 3.50%, volatile matter of 51.0%, and moisture content of 7.0%. The biochar showed an electrical conductivity of 103.33 - 119.33 S/m, an organic range of 1.66-1.95, CEC of 1.05-10.15 meq, and a pH of 8 and 7.8 before and after amendment, respectively. The SEM images showed irregular pore size with complex structure, and TGA of the biochar showed weight loss due to water lost during the heating and carbonization phase. A greenhouse trial using cowpea seedlings as an indicator to test the suitability of using coconut shell biochar in soil amendment was also carried out using a control sample and also applying 10, 30, 50, and 100 g of biochar to cowpea seedlings to assess the growth rate. The highest shoot and root weight growth was observed when the cowpea was treated with 100 g of biochar, with values ranging from 3.77 to 0.88 g respectively. Plant weights were slightly higher at higher levels of biochars added. The application of biochar is suitable for the amendment of soil to boost crop yield.

Keywords: Coconut shell, biochar, proximate composition, pyrolysis, cowpea, soil amendment.

INTRODUCTION

Soil degradation reduces the amount of organic matter and nutrients and limits its availability for plant usage and productivity [1-3]. This can be amended by using adequate soil management practices and optimizing land use systems, including biochar application [4-6]. Its application to the environment has shown significant environmental benefits, such as improving the physicochemical and biological properties of soils and significantly increasing plant growth and crop yield [7, 8]. It removes pollutants, such as phosphates, heavy metals, and organic compounds, from an aqueous medium [9, 10]. Biochar is effectively used to mitigate climate change because of its relative resistance against microbial decay and its slower return of terrestrial organic carbon as carbon dioxide (CO_2) to the atmosphere [11, 13]. Biochar could also be used as soil and water remediation due to its high surface area and microporosity, thereby minimizing negative environmental impacts [14]. In agriculture, biochar has emerged as a promising soil amendment and water remediation tool due to its unique properties and potential benefits. As an organic carbon-rich material derived from biomass, biochar can enhance soil fertility, improve water retention, soil pH, cation exchange capacity (CEC), and promote microbial activity in agricultural and natural ecosystems [15]. When incorporated into soil, biochar acts as a long-term carbon sink, effectively sequestering carbon and mitigating climate change. Its porous structure provides a habitat for beneficial microorganisms, which contribute to nutrient cycling and soil health. Biochar also improves soil structure, promoting better aeration, drainage, and nutrient availability, thereby enhancing crop productivity and resilience to environmental stresses [16].

Coconut shell, also known as coconut coir, is a fibrous material that surrounds the outer layer of a coconut. It is a byproduct of the coconut industry and has traditionally been used for a variety of purposes such as making ropes, mats, furniture, fuel, landfill, musical instruments, and other household items. Coco husk is a readily available waste material that is often discarded, leading to environmental problems. However, it contains high levels of carbon, making it a suitable material for biochar production. In addition, coco husk has a porous structure, which enhances its ability to retain water and nutrients, making it an ideal soil amendment [17, 18]. Shang *et al* [46] conducted study on the use of wood-based biochar for small fruits production in Southern Quebec. In addition Saravanan *et al* [39] reported his findings on biochar derived from carbonaceous materials for various environmental applications. Furthermore, Pranav *et al* [21] conducted a research on the fabrication of coco husk biochar for soil amendment. These results are in agreement with the present study which revealed that biochar derived from coconut shell have shown promise in soil amendment.

However, literature on biochar production using readily available agricultural feedstock like the coconut shell within Benue State, Nigeria are hardly available. Therefore, it has become imperative to research more on biochar which is an emerging and promising technology as an alternative tool for sustainable agriculture and mitigating the effects of climate changes on the soil. This study has the potential to contribute to the literature for the development of more effective and sustainable biomass like coconut shell and its possible usage in soil reclamation.

The aim of this work is to develop biochar derived from coconut biomass and determine its feasibility in soil amendment. The objectives are to synthesize, characterize, and determine the proximate composition of biochar and its efficiency in soil remediation.

MATERIALS AND METHOD

Sample collection and preparation

The sample of the biomass (coconut shell) for the production of the biochar was bought at Wurukum market in Makurdi, Benue State, Nigeria. Soil samples for the soil analysis were collected from Joseph Sarwuan Tarka University, Makurdi, Benue State, Nigeria. The soil samples were divided into two portions for two separate studies. First, the soil analysis and the other for the mixture of soil and biochar. The coconut shell was washed to get rid of impurities and sun-dried for 24 hours to reduce moisture content and was size reduced to ease carbonization

Production of biochar

The size-reduced coconut shell was carbonized in the Muffle furnace at 300 ^{o}C for 2 hours and cooled in the desiccators. Biochar was ground to powdered form using a porcelain mortar as reported by Wang *et al* [19] without modification.

Characterization

Fourier transform infrared (FTIR)

Fourier transform infrared spectroscopy analysis was performed in all samples isolated to have a prompt result regarding the biomineral. A few crystals were mixed with KBr (Merck for spectroscopy) and pulverized in an agate mortar to form a homogenous powder under a pressure of 7 tons, the appropriate pellet was prepared. All spectra were recorded from 4000 to 400 cm^{-1} using the Perkin Elmer 3000 MX spectrometer. Scans were 32 per spectrum with a resolution of 4 cm^{-1}. The IR spectra were analyzed using the spectroscopic software Win-IR Pro Version 3.0 with a peak sensitivity of 2cm^{-1} [20].

Scanning electron microscope (SEM)

Biochar was coated with platinum and placed onto a sample stub. It was inserted into the SEM instrument, and the SEM chamber was vented, allowing the chamber to reach nominal pressure (70 m Torr). The image was captured using a detector and was measured using SEM software.

Thermogravimetric analysis (TGA)

TGA was performed under an inert atmosphere using N_2 gas at a maximum heat-up rate of 20 ^oC and maximum operating temperature of 1200 ^oC while monitoring the weight loss and thermal behavior of biochar on a PerkinElmer TGA 4000 (made in Netherlands). The analysis enabled the observation of changes in physical and chemical properties of biochar as a function of temperature [21].

Seed preparation and seedling preparation

Polythene bags of length 14 cm and diameter 11 cm were selected for the experiment. A delicate fabric cloth was placed on the bottom of the polythene bags. The different polythene bags were filled with 5 g of soil treated with biochar of different application weight (10 g, 30 g, 50 g, 100 g) and others filled with control. Two cowpea seeds were sown at a depth of 2 cm and covered with propagation mix. The planted samples were watered twice a day, immediately after seeding. Just after germination, the seedlings were thinned to one seedling per cell. The painted samples were kept in an air-conditioned bay of a glasshouse to protect the seedlings from high-temperature stress. Seedlings were watered every morning and evening until they germinated. After germination, the watering was reduced to once every alternate day to harden seedlings. The plants were monitored weekly to determine the growth rate, and the plants were later uprooted for further analysis [23].

Plant analysis

The cowpea was uprooted, washed and dried at room temperature for 1 hour. The fresh shoot and root were cut into pieces and weighed to obtain fresh shoot and root weight. Then, the sample was dried in an oven for 24 hours at 200 ^{o}C and was weighed to obtain the dry shoot and root weight [24].

Determination of pH

The pH was determined by weighing 10 g of air-dried soil into a 50 mL plastic beaker, and 25 mL of distilled water was added and stirred for 30 minutes and was left to stand undisturbed for another 30 minutes. The pH meter was calibrated using pH buffers 4, 7 and 9. The electrode of the pH meter was immersed in the soil water suspension, and the reading was taken after 30 seconds. The above procedure was repeated using 0.01M $CaCl_2$ and 1N KCl solutions. The reading was recorded as the pH in water, 0.01M $CaCl_2$ and 1N KCl. This was repeated for soil samples mixed with biochar [25].

Determination of organic carbon (OC)

The organic carbon was determined by weighing 1 g of the soil sample into a 250 mL Erlenmeyer flask, and 5 mL of 1 N $K_2Cr_2O_7$ was added using a pipette and gently swirling to dispense the soil. About 10 mL of concentrated H_2SO_4 was rapidly added and swirled for 1 min. The flask was allowed to stand on an asbestos sheet for 30 minutes to cool. O-phenanthroline ferrous sulphate indicator (5 drops was added and titrated with ammonium ferrous sulphate solution with a white background. The blue color change determines the end point of the titration. A blank was also determined using the procedure but without soil [26].

The percentage of organic carbon was determined using Equation 1:

$$\% \text{ Organic Carbon (OC)} = \frac{(Blank\ Titre - Actual\ Titre) * m * f}{mass\ of\ air\ dry\ soil\ taken} \quad (1)$$

$$\text{Percentage Organic Matter (\% OM)} = \% \text{ OC} * 1.724 \quad (2)$$

This was repeated for soil samples mixed with biochar.

Cation exchange capacity

This was done using the ammonium saturation method. In this method, 10 g of soil sample was weighed into 100 cm^3 and 40 mL of 1N pH 5 mL ammonium acetate was added and stirred with a glass rod and left to stand overnight. The soil was filtered with light suction using a 55 mm Buchner funnel (corning size No. 40). The leachate from the soil was tested with a few drops of ammonium oxalate to determine if it was calcium-free and heated. A white precipitate indicates the presence of calcium. The soil was leached four times with 1N NH_4Cl pH 7 with 25 mL at a time and once with 0.25 N pH 7 NH_4Cl, and the solution was discarded. The electrolyte was washed with 150 mL of Isopropyl alcohol. The chlorides were also leached out of the soil with 0.1 N $AgNO_3$ till leachate became negligible. The soil was then leached with acidified NaCl to a volume of 250 mL, 50 mL of 2% boric acid was measured into a conical flask, and two drops of mixed indicator were added. The acidified NaCl solution was poured into a 500 mL Kjeldahl flask, and the flask was connected to the distiller 10 mL 1N NaOH and some anti-bumping was added into the flask and distilled over boric acid in the conical flask. About 150 mL of the distillate was collected and titrated with standard 1 N HCl solution, a blank solution carried out the same but with soil sample, and CEC determined using Equation 3 [27].

$$\text{ECin meq per 100 g soil} = \frac{(Titre - B) * NA * 100}{mass\ of\ soil} \quad (3)$$

Where B= blank

This was repeated for soil samples mixed with biochar.

Determination of moisture content

A clean and labelled moisture can, which has been oven-dried weighed (W_1), and enough soil samples were added in the moisture can and weighed (W_2). The moisture can containing the soil sample was transferred into a thermo-setting oven at 110 ºC for 24 hours. It was removed and cooled in the desiccator for 1 hour and weighed (W_3).

The Moisture content of the soil was calculated using Equation 4 [28].

$$\% \text{ Moisture} = \frac{loss\ in\ weight}{wt.of\ the\ soil\ sample} * 100 \qquad (4)$$

Determination of particle size

The particle size was determined using the Bouyoucos hydrometer method. In this method, 50 g of 2 mm sieved soil was weighed into a 250 mL plastic beaker and 100 mL of 50 % calgon was added into the beaker and was stirred with a glass rod. Then, 100 mL of distilled water was added and stirred. The beaker was left to stand for 30 minutes with occasional stirring. The sample was transferred into the mixing cup and was shaken for five minutes; the sample was transferred into a 1000 cm^3 measuring cylinder and was made to 1000 cm^3 mark with distilled water. The suspension was mixed vigorously with an extended hand plunger, ensuring the sediments at the bottom were disturbed before taking the hydrometer reading. The hydrometer reading took 40 seconds and 2 hours at the upper meniscus by deepening the hydrometer into the suspension. A blank was prepared by mixing 100 mL of distilled water with 50 % calgon and was made up to the 1000 mL mark, and the hydrometer reading taking also at 2 hours and 40 seconds. The temperature of the blank and that of the suspension were taken. After the hydrometer reading, the suspension was poured through a 0.2 mm sieve and washed with water to retain the sand grains. It was transferred into a beaker dried in an oven at 105 ^oC, and was weighed. This gives the coarse sand fraction [29].

The corrected hydrometer reading C (g/L) was obtained as follows;

$$C = R - RL + (0.36T) \qquad (5)$$

C is the corrected hydrometer reading, R is the hydrometer reading in the soil suspension, and RL is the hydrometer reading in the blank. 0.36 T factor for every degree above 20 ^oC

The percentage by weight of Silt + Clay + Sand fractions were obtained using Equations 6, 7 and 8

$$\text{Clay } \% = \frac{Corrected\ 2h\ \ reading - Blank}{Mass\ of\ the\ soil} * 100 \qquad (6)$$

$$\% \text{ Silt} = \frac{Corrected\ 40\ secs\ reading - Blank}{Mass\ of\ the\ soil} * 100 \qquad (7)$$

% Sand = 100 - (% Clay + % Silt). (8)

The sample was then classified according to the International Systems of Textual Classification.

Determination of bulk density (BD)

The bulk density of the sample was determined by collecting the soil sample from the depth using a sharp-edged cylindrical soil auger of 5 cm internal diameter. The auger was carefully driven into the so that negligible compaction can occur. The weight of the sample was taken in the field. After weighing the sample, it was oven-dried at 105 °C until constant weight was achieved.

The BD was determined by using Equation 9 [29].

$$BD\ (g/\ Cm^3) = \frac{mass\ of\ the\ dried\ soil\ sample}{Volume\ of\ the\ soil} \quad (9)$$

Determination of electrical conductivity (EC)

Soil-water (1:5) suspension was prepared by measuring 10 g of soil into 50 mL distilled water and was mechanically shaken at 5 rpm for 1 hour. The conductivity meter was calibrated with a KCl reference solution to obtain the cell constant. The cell was rinsed thoroughly, and the EC of the suspension was measured at the same temperature as that of the 0.01M KCl. The conductivity cell was rinsed thoroughly and refilled with soil suspension without disturbing the settled soil, and the value indicated on the conductivity meter was recorded.

Determination of porosity using Stochastic Method

The soil sample of 200 g was weighed into a beaker and was filled with the beaker. The porosity was determined by measuring the volume of water poured and the total volume of the material expressed in percentage [30].

$$Porosity = \frac{volume\ of\ water}{total\ volume} * 1000 \quad (10)$$

RESULTS AND DISCUSSION

Table 1 shows the mean values for the number of leaves, fresh shoot weight and dry shoot weight in response to biochar application.

Table 1: Performance of biochar on the number of leaves, fresh shoot weight and dry shoot weight of cowpea.

Biochar rates (g)	No of Leaves	Fresh shoot weight (g)	Dry shoot weight (g)
Control	7	1.65±0.42	0.40±0.10
10	7	1.82±0.25	0.47±0.03
30	9	1.67±0.03	0.41±0.03
50	11	2.47±0.47	0.63±0.04
100	13	3.73±0.17	0.88±0.15

Table 2 shows the result of the physical and chemical properties of the analyzed two soil samples without the addition of biochar.

Table 2: Physico-chemical properties of soil samples without application of biochar

	Samples	
Parameters	A±SD	B±SD
pH	8.78± 0.00	8.78 ± 0.00
Volatile organic carbon (%)	51.00± 0.00	51.00±0.00
Organic matter (%)	1.66±0.00	1.95±0.00
Electrical conductivity (μScm^{-1})	119.33±0.22	103.33±0.67
Cation exchange capacity (Cmol/Kg)	1.05±0.01	10.15±0.01
Bulk density	1.45±0.00	1.46±0.00
Porosity (%)	45.29±0.10	45.03± 0.13
Moisture (%)	7.01±0.05	6.80±0.20
Clay (%)	20.29±0.14	19.92±0.09
Sand (%)	68.36±0.05	68.36±0.05
Silt (%)	11.35±0.21	11.67±0.22

Ash content (%)	3.50±0.00	2.80±0.01
Texture	Loamy	Loamy

Table 3 shows the physico-chemical properties of the analyzed soil samples on application of the synthesized biochar (coconut shell)

Table 3**:** Result of the Biochar - Soil (1:15) Analysis

	SAMPLE	
Parameters	A ± SD	B ± SD
pH	5.77±0.00	5.77±0.00
Organic carbon (%)	1.13±0.00	1.13±0.00
Organic matter (%)	1.95±0.00	1.95±0.00
Electrical conductivity (µScm^{-1})	100.33±2.89	103.33±7.54
Cation exchange capacity (Cmol/Kg)	10.14±0.00	10.15±0.00
Clay (%)	21.07±0.50	20.70±0.40
Sand (%)	67.60±0.13	67.65±0.13
Silt (%)	11.33±0.2	11.61±0.20

Figure 1 shows the result of Fourier Transform Infrared analysis of the produced biochar

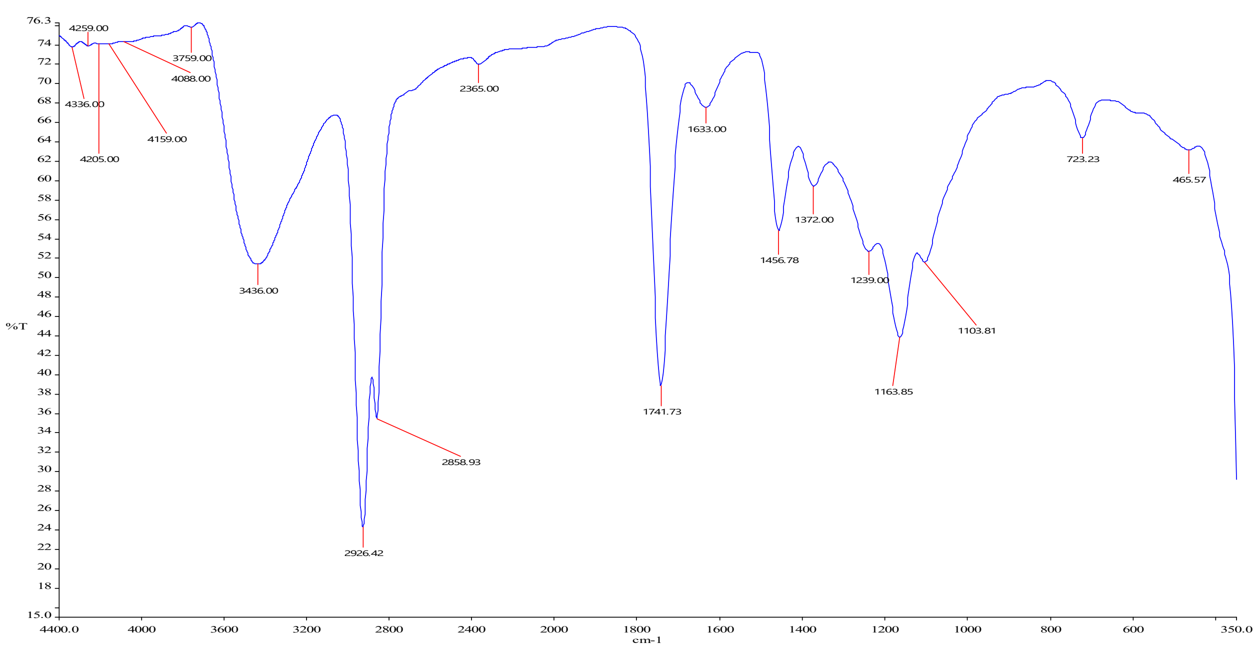


Figure 1. FTIR Analysis of coconut shell biochar

The Thermogravimetric analysis of the synthesized biochar is presented in Figure 2

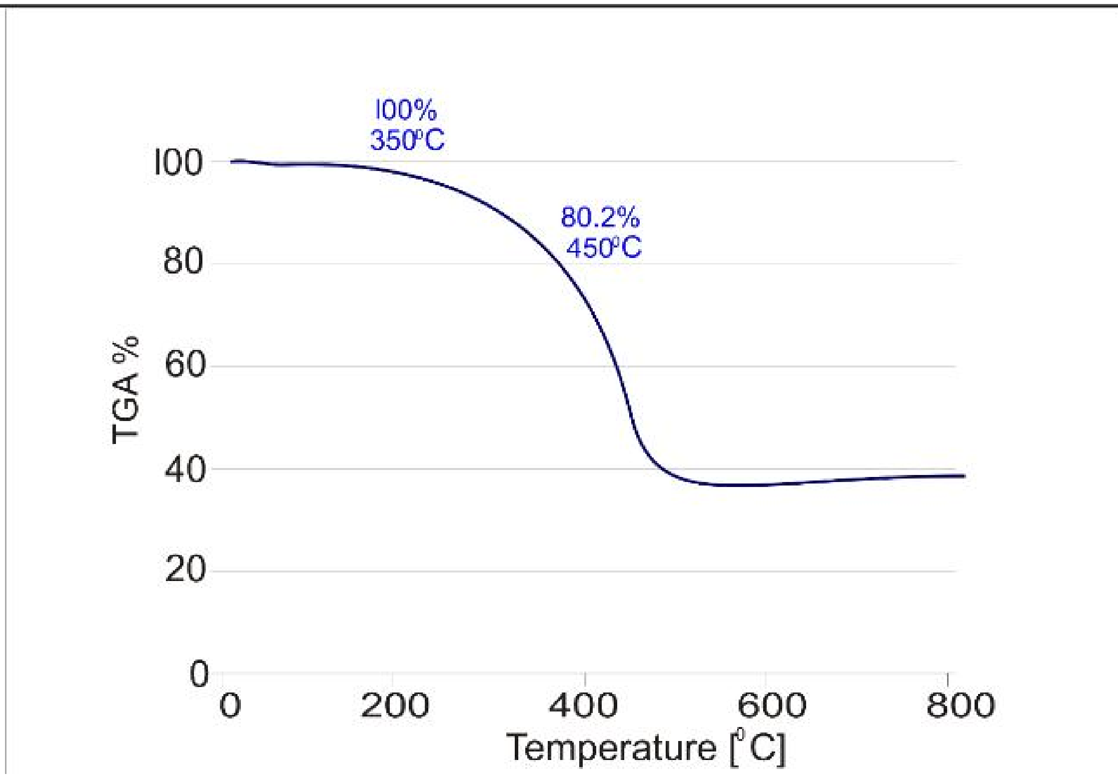
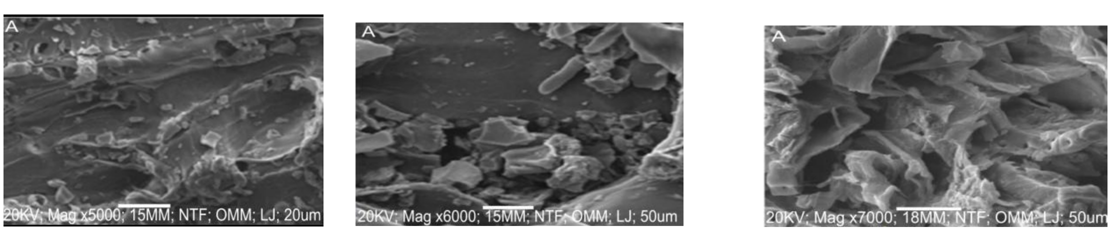


Figure 2. Thermogravimetric Analysis (TGA) curve of the synthesized biochar under a heating of 20 °C min^{-1} in an atmosphere of nitrogen

The result of Scanning Electron Microscope showing the morphology of the biochar is presented in Figure 3a, b and c.



(a) (b) (c)

Figure 3. Micrographs of the biochar (a) (b) (c) after carbonization at 500x, 600x and 700x magnification

Plate 1 shows the image of cracked coconuts shell feedstock (biomass) prior to pyrolysis

Plate 1: Coconuts shell feedstock used for biochar production

The fresh coconut were soaked into water for 2 h to loosen the shells, Then removed and placed on a hard surface and hit gently with a hammer around the equator until the shell cracks opened, and were carefully separated from coconut meat prior to hydrothermal carbonization of the biomass.

Growth analysis

The average weight of the cowpea from pot 1 had the highest number of plant leaves (13) within the individual treatment pot that is treated with 100 g of coconut shell biochar, as shown in Table 1. A large amount of biochar affected the fresh weight of cowpea shot and root (3.73 and 0.88g), respectively. Pot 2 shows an increase in average number of leaves (11) when treated with 50 g of biochar. The amount of biochar affected the fresh weight of the cowpea shoot and root (2.47±0.47 and 0.63±0.04 g) and the dry weight of the shoot and root, respectively. Furthermore, compared to the control pot, there was no significant effect on the cowpea plant. Generally, the growth rate in terms of weights increased for all treatments, while the controlled treatment recorded the lowest rate of crop weight, ranging from 1.65±0.04 to 3.73±0.17 g. The highest fresh weight rate was recorded with 100 g of biochar, 50 g, and 30 g of biochar application. The increased rate in the weight of cowpeas treated with biochar was recorded at six weeks. There was a slow increase rate of leaves between week 1 and week three due to the increase in pH and nutrient imbalance associated with fresh biochar. It was observed that the average number of leaves in the controlled sample faded color compared to the treated pots with a greenish color. This could be attributed to the deficiency of nutrients in the controlled sample [31, 32]. This result is in agreement with that reported by You *et al* on the use of biochar as an emerging soil amendment and its potential ecological risk.

The result presented in Table 2 shows the analysis of both the physical and chemical properties of the analyzed two soil samples. The result revealed that the pH of the two soil samples analyzed is 8.78± 0.00, which indicates that the soil samples are strongly alkaline [33, 34]. The organic carbon, as revealed from the result, is 51.00.± 0.00 % for both samples, while the organic matter is 1.66±0.00 and 1.95±0.00% for Sample A and B, respectively. These results are in agreement with previous research reported by Singh *et al* on the influence of biochar applications on soil physical and chemical properties, microbial diversity, and crop productivity [47]. Soil organic matter significantly improves soil capacity to store and supply nutrients (N, P, K, Ca, and Mg). The EC of the soils, as revealed from the results, show 119.33±0.22 μScm^{-1} and 103.33±0.67 μScm^{-1} for samples A and B, respectively. The values of CEC, as shown from the results ranges from 1.05±0.01 and 10.15±0.01 Cmol/Kg for samples A and B, respectively. CEC measures the ability of soil to hold cations by electrical attraction [35, 36]. The result shows that the bulk density of the soil is 1.45±0.00 and 1.46±0.00 g/ Cm^3 for Sample A and B. Bulk density impacts available water capacity, root growth and movement of air and water through soil [37]. This agrees with the findings of Yi *et al on* water retention of biochar-amended soil from independent measurements of biochar and soil properties [22]. The porosity of the soils, as shown from the result in Table 2 is 45.29± 0.10 % and 45.03 ± 0.13% for samples A and B. The porosity of the soil is inversely proportional to bulk density [38]. The particle size, as revealed from the results, shows 20.29±0.14% and 19.92±0.09% clay, 68.36±0.05% sand, and 11.35±0.21% and 11.65± 0.22% Silt for samples A and B, respectively. This indicates that the soil constitutes a higher percentage of sand. Similarly, the texture of the soil, as revealed from the result is loamy [39].

The result in Table 3 shows the effect of biochar on both the physical and chemical properties of soil. The result shows that the pH of both samples is 5.77±0.00 which in comparison to the pH shown in Table 2 indicates an increase in the acidic condition of the soil by 0.33%, which agreed with the previous works [40, 41]. The organic content and organic matter revealed from the results is 1.13 ± 0.00% and 1.95 ± 0.00% for both samples. This also shows an increased organic content of 0.4% and organic matter of 0.29% for sample A and 0.28% for sample B. This is in agreement as reported in previous works [42, 43]. The EC, as revealed from the result, is 100.33±2.89 μScm^{-1}and 103.33±7.54 μScm^{-1}, as compared to the EC shown in Table 2. This study has revealed that adding biochar to the soil decreases the EC of the soil. Soil electrical conductivity is a measure of the amount of salts in soil. Excess salts hinder plant growth by affecting the soil- water balance [42]. These results tallies with of Kumar *et al* [26] who opined that coconut biochar has the potential to reduce soil EC. The CEC, as revealed by the result, is 10.14±0.00 μScm^{-1} and 10.15±0.00 μScm^{-1}. The CEC of the soil has increased as compared to the CEC of the addition of biochar to the soil sample. This is an indication that biochar has the ability to increase CEC, which tends to improve soil fertility by supplying nutrients like N, K, and P as earlier reported by Abedin and Atotaibi [43, 44]. The result also shows an increase in the particle size, 21.07 ± 0.50% and 20.70 ± 0.4% Clay, 67.60±0.13% and 67.65±0.13% sand, and 11.33± 0.2% and 11.61±0.2% Silt for sample A and B respectively. In comparison to the result of the particle size shown in Table 2, the addition of biochar decreases the sand fraction of the particle but has little or no effect on the clay and silt fraction of the soil and soil texture. Similar results were obtained by Adekiya *et al* on the effect of biochar on soil properties, soil loss, and cocoyam yield on a tropical sandy loam alfisol [3].

The result shown in Figure 1 displays the spectrum obtained from the FTIR result of the produced biochar, which accounts for the functional groups present in the biochar. From the spectrum, 17 functional groups have been detected; 12 ranging from 1500-4000 cm^{-1} are group regions, while 5 ranging from 300-1500 cm^{-1} are fingerprint regions. Six N-H functional groups have been identified at a wavelength of 3759.00, 4088.00, 4159.00, 4205.00, 4259.00, and 4336.00 cm^{-1}, one O-H functional groups was detected at the wavelength of 2926.42 cm^{-1}, one C-H functional at 2858.93 cm^{-1} one spectra is detected at 2365.00 cm^{-1} which is likely a functional group of C-C triple bond or C-N triple bond, C-O double and C-N double were detected at 1741.73 cm^{-1} and 1633.00 cm^{-1} respectively. The presence of N-H functional groups in high concentration could be responsible for the highly alkaline nature of biochar. Hence compound with N-H of Nitrogen heteroatoms (alkaloids and amine) are mostly alkaline. This finding is in agreement with that of Conte *et al* [48]. This has proven why biochar is used as a liming agent and other important soil properties as researched by Hung and Shang [45, 46].

The TGA of the produced biochar, as shown in Figure 2 indicates that the thermal decomposition of biochar, the weight loss reaching 100% occurred at 100 ^{o}C, which can be attributed to the evaporation of water bound inside the biochar pores [47]. This condition slowly decreases to 450 ^{o}C, this temperature can be associated with the carbon decomposition phase [48].

The morphology of the biochar produced, as presented in Figure 3, revealed that the biochar looks rough with irregular pore size with complex structures, which are formed due to loss of volatile substances after carbonization at 300 ^{o}C. The remaining non-volatile components are then transformed into biochar with pores of various shapes and sizes observed on the surfaces. [49, 50].

CONCLUSION

Applying biochar for soil amendment is beneficial for plant growth and soil conditioning, as seen in this study. It improved the electrical conductivity of the soil, porosity, bulk density, particle size, organic carbon, volatile organic matter, pH and cation exchange capacity. Therefore, improvements in soil physical, chemical, and biological properties promote the productivity of plants through increasing the amount of nutrient elements, enhancing the availability of nutrient elements, reducing nutrient leaching, and mitigating nutrient losses.

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