



Effect of Biochar on Soil Properties and Organic Carbon Sink in Degraded Soil of Southern Guinea Savanna Zone, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author EN designed the study, wrote the protocol and wrote the first draft of the manuscript. Author SMA managed the literature searches, analyses of the study performed the spectroscopy analysis and author CLAA managed the experimental process and author EN identified the species of plant. All authors read and approved the final manuscript.

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ABSTRACT

Biochar incorporation into soil has been shown to improve the soil quality for crop production and sequestered organic carbon into the soil thereby mitigating climate change. The experiment was conducted during 2010 rainy season at the research and teaching farm of the college of agriculture, Lafia, Nasarawa state, Nigeria. To evaluate the effect of biochar on soil properties and the amount of organic carbon that can be sequestered in the soil. The treatments consist of biochar rates: 0, 5 and 10t/ha laid in Randomized Complete Block Design (RCBD). 10t/ha of biochar produced the highest levels of (pH, = 6.91; %Total Nitrogen, =0.38; K, =1.59; %Organic Carbon, = 0.56; Mg, = 2.50 and Cation Exchange Capacity = 11.35) compare to the other rate and control. However, application of 5t/ha of biochar did not show any significant effect compared with the control. Biochar

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application did not show any significant effect on sand, clay and silt; but had a significant effect on % organic matter, bulk density and %porosity. Application of 10t/ha of biochar produced the highest value of 7.67% silt and clay; but sand particles and bulk density decreases with increased rates of biochar application. Therefore, the control produced soils with the highest values of sand particles of 87.33% and bulk density of 1.68g/cm. Also, there is a significant difference in total quantity of carbon sequestered at the different rates of biochar application. 10t/ha sequestered a largest quantities of 1352.40t/ha of soil organic carbon. The lowest carbon stored of 926.85t/ha was reported in control plot. The result of this study suggest that biochar additions to the soil produced general improvement of soil qualities, with the possibility of lowering the soil acidity and increasing organic matter and organic carbon sink which has the capacity to improve crop production and mitigate climate change.

Keywords: Biochar; soil organic carbon; physical properties; carbon sink and degraded soil.

1. INTRODUCTION

Arable lands all over Nigeria have seen an alarming decline in soil productivity as a result of continuous agricultural practices without application of adequate restorative measures to revitalize the soil [1]. Biochar is a stable form of charcoal produced from heating natural organic materials (crop biomass, woodchips, manure and other agricultural waste) in a high temperature of below 1000°C and low oxygen. Biochar additions to soil have shown various benefits, including improvements in soil quality [2-6]. Adding biochar may increase exchangeable potassium (K) levels in soil through both the addition of K which is in the ash fraction of the biochar and by reducing losses of K through leaching [6,4,2]. Biochar incorporation into soils has been shown to increase exchangeable Ca in some experiments [6,4,5], but in other experiments biochar did not have a measurable effect on exchangeable Ca [2]. Similar results have been reported for exchangeable Mg [6,4,5]. Soil pH has increased in most studies reporting effects of biochar additions on soil pH [6]. Temperature increases have now been proven and are occurring with an unprecedented rate [7]. Carbon dioxide (CO₂), methane (CH₄) and nitrous oxides (NO₂) are important drivers of the anthropogenic greenhouse effect. These gasses are released both through burning of fossil and biomass fuel as well as decomposition of organic matter. There has been a sustain efforts aim at reducing avoidable greenhouse gas emissions through sequestration of C in the environment. As regards sequestration, many different strategies are discussed in the literature, ranging from wide-spread afforestation and reforestation to pumping of CO₂ into ocean and geological layers [8]. For terrestrial ecosystems it has been proposed that carbon sequestration can be

increased by increasing soil carbon stocks [9-11]. Such a proposal is sensible given the fact that more than 80% of the terrestrial organic carbon stores are contained in soils [8]. The consensus appears to be that soil represents a finite carbon sink at best and will only provide a window of opportunity for reducing carbon emissions or exploring other opportunities for carbon sequestration [12,13] and that these carbon sinks may have a low permanency and can be easily depleted upon land use change [14]. The conversion of biomass to bio-char as a carbon sink has been proposed before [15] but was not explicitly linked to an application to soil. Land application of bio-char is not a new concept. For example, certain dark earths in the Amazon Basin (so-called Amazonian Dark Earths or “*terra preta*”) have received large amounts of charred materials, the residues from biomass burning [16]. Large amounts of bio-char derived carbon stocks remain in these soils today, hundreds and thousands of years after they were abandoned. The total carbon storage is as high as 250MgCha⁻¹ m⁻¹ compared to typical values of 100MgCha⁻¹ m⁻¹ in Amazonian soils derived from similar parent material [17]. Agricultural production is now suffering from land degradation due to poor management strategies and practices; continuous cultivation which causes a decrease in soil fertility and depletes soil biodiversity and increase atmospheric Greenhouse gasses which result to higher temperatures (Global warming). Biochar could serve as one of the tools in addressing these problems of agriculture and Global warming. The aim of this study was to evaluate the effect of biochar on physical and chemical properties of the soil and amount of carbon that can be stored in the soil.

2. MATERIALS AND METHODS

2.1 Climatic Description of Experimental Site

The experiment was conducted during 2010 rainy season at the research and teaching farm of the college of agriculture, Lafia, Nasarawa state, Nigeria. The study area falls within southern guinea savanna agroecological zone of Nigeria, and is located between Latitude 08.33N and Longitude 08.32E. Rainfall usually starts from March – October and the average monthly rainfall figures ranges from 40mm-350mm. The months of July and August usually records heavy rainfall. The daily maximum temperature ranges from 20.0°C–38.5°C and daily minimum ranges between 18.7°C–28.2°C. The months of February to early April are the months that have the highest maximum temperature while the lowest maximum temperature months are recorded in December and January because of the prevailing cold harmattan wind from the northern part of the country at this period. The relative humidity rises as from April to a maximum of about 75- 90 percent in July [18].

2.2 Description of Soil and Vegetation of the Experimental Site

The soil type of the study area composed of highly leached ultisols with low base saturation. The soil is strongly acidic and has high content of iron and Aluminium oxides hence reddish brown in colour with very low organic matter content and low total nitrogen and available phosphate. The dominant clay type is Kaolinite. The vegetation of the study area is that of the southern Guinea Savanna with interspersions of thicket, grassland, trees, fringing woodlands or gallery forest along the streams. The natural vegetation of the area is made up of grasses and some traces of scattered wild and economic trees like *Vitellaria paradoxa* (Shear butter tree); *Parkia* spp (locust bean tree); *Gmelina arborea* (beechwood); *Anacardium* spp (Cashew trees); *Magnifera indica* (Mango). These trees usually shed off their leaves in the long dry season to conserve the available water.

2.3 Experimental Design and Data Collection

The treatments consisted of three levels of biochar: 0, 5 and 10t/ha were laid in a Randomized Complete Block Design (RCBD)

and replicated three times to form nine plots. The plot size was 3 m by 4 and 0.5m between plots and 1m between replicates. The data for this study were collected from 9 soil samples at the depth of 15cm from experimental plots were three rates (0, 5, and 10t/ha) of biochar were incorporated into the soil. The biochar of hard wood bought from a local distributor was manually crushed to particle sizes smaller than 2 mm and incorporated at different rates into the soil. The sizes of the three experimental plots were 16m² each and they were close to each other within the same climatic region, relief, parent material and soil types. This makes comparison of soil properties between the different biochar rates possible. Then each plot was divided into three strata and three composite soil samples were collected from each plot and bulk together to form a bulk soil sample per plot, so that the land will be adequately covered and the soil of the entire land will have equal opportunity to be collected without bias. Core method was also carried out in the field for determination of bulk density of the soil. All the samples were collected after 2years of cropping the land with maize.

2.4 Laboratory Analyses

The soil samples were collected air-dried, and thoroughly mixed, then passed through 2mm sieve mesh to obtain a homogeneous particle sizes, after which standard laboratory procedures as described by [19] was used to determine both physical and chemical properties of these bulk soil samples. The Macro-Kjeldahl method was used to determine the total nitrogen in the soil samples. Available phosphorus was determined using extractable solution of sodium bicarbonate Na (HCO₃)₂. (Olsen 1945 method). Exchangeable bases were determined using flame atomic absorption spectrometry and the concentration of potassium was determined using the flame photometer. The organic carbon was determined using the Walkley-Black chromic acid titration method. Soil pH was determined using the electrometric method. Cation exchange capacity (CEC) is determined using ammonium acetate method; that is measuring the total amount of a given cation needed to replace all the cation from a soil exchange site and it is expressed in centimoles per 100 gram soil (Cmol/100g soil). The bulk density was determined by using core sampler. The percent total porosity was computed from the bulk density assuming a particle density of 2.65cm⁻³.

The calculation of organic matter was done using the formula by [19].

$$\text{Organic Matter (\%)} = \frac{\text{Soil Organic Carbon (\%)}}{1.72} \quad (1)$$

The carbon density (t/ha) per soil layer is calculated using the formula by: [20].

$$\text{C d} = \% \text{ C} \times \text{bulk density (cm}^3\text{)} \times \text{soil layer depth (m)} \times 10000(\text{m}^2\text{/ha)} \quad (2)$$

The data collected were subjected to analysis of variance using GENSTAT, and where there is a significant difference; the means were separated using F-LSD at 5% probability level

3. RESULTS

The chemical analysis of the soil (Table 1), before incorporating biochar showed that nitrogen, phosphorus, potassium, organic carbon and cation exchange capacity were very low. The soil was also strongly acidic in nature (pH: 5.18). The biochar material contained higher quantities of 64.16kg/mg carbon and carbon/nitrogen ratio of 78.23mg/kg.

The result of soil properties under different biochar treatment sampled after two years of maize cropping are presented in Table 2. The result showed that biochar application had a significant effect on all the chemical properties of the soil except on sodium. Increased biochar application resulted to gradual increase in most of the chemical properties in the soil except H+Al. 10t/ha of biochar produced the highest levels of (pH, = 6.91; %TN, =0.38; K, =1.59; %OC, = 0.56; Mg,= 2.50, and CEC= 11.35) compare to the other rate and control. However, application of 5t/ha of biochar did not show any significant effect compared with the control.

Result of the study in Table 3, revealed that biochar application did not showed any

significant effect on sand, clay and silt; but had a significant effect on % organic matter, bulk density and % porosity. Application of 10t/ha of biochar produced the highest value of 7.67% silt and clay, 85.33% of sand. However, sand particles and bulk density decreases with increased rates of biochar application. Therefore the control produced soils with the highest values of sand particles of 87.33% and bulk density of 1.68 g/cm³.

Table 1. Laboratory analysis of soil sample and biochar before planting

Soil properties @ 15cm	Soil	Biochar
Mechanical composition		
Clay (g/kg)	8.64	Nd
Silt	26.21	Nd
Sand	65.22	Nd
Textural classification (USD)	Sandy loam	
Ash content (%)	Nd	15.30
Chemical composition		
pH(H ₂ O)	5.18	8.15
pH(0.01M CaCl ₂)	5.04	7.82
T N%	0.13	0.82
Avail. P(ppm)	18.08	3.84
K(mg/kg)	0.16	5.43
OC(mg/kg)	0.42	64.16
C/N	3.23	78.23
Mg(mol/kg)	0.49	1.92
Ca(mol/kg)	4.34	1.51
Na(mol/kg)	0.85	1.83
CEC(mol/kg)	4.75	78.25

nd= not determined

Results of the study showed that there were significant differences in total quantity of carbon sequestered at the different rates of biochar application (Table 4). Application of 10t/ha sequestered a largest quantities of 1352.40 t/ha of soil organic carbon. The lowest carbon stored of 926.85 t/ha was reported in control plot.

Table 2. Effect of biochar on chemical properties of degraded soil

Treatment Biochar (t/ha)	pH ratio		(%)		(ppm)		(Cmol/kg)				
	H ₂ O	0.01 CaCl ₂	OC	TN	Av. P	Ca	Mg	K	Na	H+Al (Acidity)	CEC
0	6.25	5.54	0.37	0.18	14.16	4.43	1.00	0.70	0.45	0.59	6.51
5	6.65	5.77	0.44	0.37	12.61	4.22	1.22	0.86	0.41	0.48	6.25
10	6.91	5.83	0.56	0.38	13.37	6.34	2.50	1.59	0.42	0.43	11.35
LSD(0.05)	0.38	0.17	0.03	0.04	0.51	0.57	0.46	0.46	0.04	0.03	0.34
S.E.M	0.13	0.06	0.03	0.01	0.18	0.21	0.17	0.16	0.16	0.01	0.12

LSD= least significant difference; S.E.M= Standard error of mean

Table 3. Effect of biochar on physical properties of degraded soil

Treatment Biochar(t/ha)	Particle distribution (%)				% Org. matter	Bulk density (g/cm ³)	% porosity
	Sand	Clay	Silt	Tex. class			
0	87.33	6.33	6.33	Sand	0.67	1.67	36.61
5	87.00	7.67	6.33	Sand	0.76	1.63	38.44
10	85.33	7.67	7.67	Sand	0.96	1.61	39.63
LSD(0.05)	2.51	1.51	1.51		0.03	0.03	0.06
SEM	0.54	0.54	0.54		0.01	0.01	0.23

LSD= Least significant difference S.E.M= standard error of mean

Table 4. Effect of biochar on quantity of organic carbon stored (t/ha) at 0-15cm of soil

Biochar (t/ha)	% Org. carbon	Bulk density (g/cm ³)	Carbon density (t/ha)
0	0.37	1.67	926.85
5	0.44	1.63	1075.80
10	0.56	1.61	1352.40
LSD(0.05)	0.03	0.03	0.91
SEM	0.01	0.01	0.33

LSD= least significant difference; S.E.M= standard error of mean

4. DISCUSSION

The study revealed that the soil was strongly acidic before the incorporation of biochar. This confirmed the findings of [21] who reported that the soils around Nasarawa state were acidic. While the biochar material contained higher quantities carbon and carbon/nitrogen ratio. Therefore, this signified that the decomposition of the biochar material will continue at the maximum rates and nitrogen will be released for use by crops and other micro organisms in the soil. Biochar incorporation into the soil as soil amendment improved the both the physical and chemical properties of soil for crop production. This is in conformity with the work of [22] who reported that Biochar used as a soil amendment, can boost soil fertility and improve soil quality by reducing soil acidity, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving cation exchange capacity (CEC), and retaining nutrients in soil. [23], also reported that biochar enhances the water retention capacity of soils, thus improving dry or sandy soils and reducing irrigation requirements. The main mechanism behind the increased water holding capacity and improved saturated hydraulic conductivity can be attributed to the modification of the soil's porosity. Sandy soils have low water holding capacities, due to a dominant macro-and meso-pore systems

present, with little to no organic material and/or clay at hand. Bulk density is another key parameter to note, because it is directly affected by the application of biochar. The effect is possibly due to the modification in bulk density; before amendment of soil with biochar, the soil was more compacted and therefore a higher bulk density present, and with biochar amendment the soil strength decreased as the bulk density also decreased. These findings are in consonance with the recent research work by [6,24] who reported a decrease in soil bulk density after biochar additions, but increases in soil porosity and soil aeration. This may have a positive effect on root and microbial respiration. Biochar has a very low bulk density and particle density [25], hence for the volume it occupies within the soil and its low mass due to its porous nature. Another major benefit associated with the use of biochar as a soil amendment is its ability to sequester carbon from the atmosphere and transfer it into the soil thereby mitigating climate change [26]. The sequestration potential for biochar in this study is highly significant; which is in agreement with report of [22] who predicted that the biochar storage capacity of global cropland and temperate grassland is going to be 400Gt C, which would be equivalent to 25% increase in global soil carbon. Biochar may persist in soil for millennia because it is highly resistant to microbial decomposition and mineralization. However, this particular characteristic of biochar depends strongly on its properties. No wonder, [27], discovered that the stability of biochar in the soil is affected by the pyrolysis conditions and the type of feedstock used in its production.

5. CONCLUSION

In conclusions, this study showed that soil amendment with biochar improves both the soil quality for increased crop production and sequestration of soil carbon. Biochar has very promising potential for the further development of

sustainable agriculture production systems. Also, biochar production provides a great potential for worldwide climate change mitigation. The research on the many complex issues related to biochar production systems is growing very quickly and will be needed to more fully understand the implications for food production, the environment and also bioenergy production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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