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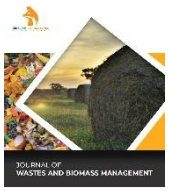

RESEARCH ARTICLE

EFFECT OF TECTONA GRANDIS BIOCHAR ON SOIL QUALITY ENHANCEMENT AND YIELD OF CUCUMBER (CUCUMIS SATIVUS L) IN HIGHLY-WEATHERED NITISOL, SOUTHEASTERN NIGERIA

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ABSTRACT

The study was conducted to assess the "Effect of Tectona grandis Biochar on Soil Quality Enhancement and Yield of Cucumber (Cucumis sativus L) in highly weathered Nitisol, Southeastern Nigeria" . The study was laid out as a randomized complete block design (RCBD) with five treatments (0 t ha^{-1}, 2.1 t ha^{-1}, 3.4 t ha^{-1}, 4.7 t ha^{-1} and 6.0 t $ha^{-1}$of biochar rates) and four replications. Data were collected from both soil and plant properties. Soil samples (0 to 20 cm) were collected before and at harvest from different plots for soil physical and chemical analyses. Results showed significantly increase ($P<0.05$) in soil physical properties (bulk density and hydraulic conductivity), chemical and exchangeable bases (pH, N, P, K, Ca, Na, Mg, CEC and BS) under field conditions in response to application of different rates of biochar, and was consistent with the plots amended with biochar relatives to control plots. Biochar applied at 4.7 t ha^{-1} resulted to the highest significant improvement ($P<0.05$) in all the agronomic parameters compared to other biochar application rates with biochar applied at 3.4 having the highest agronomic efficiency of 96.2%.

KEYWORDS

Biochar, cucumber, soil characteristics, soil improvement, Crop performance

1. INTRODUCTION

Soil is an essential resource for sustainable agriculture and food production. The risk of rapid soil degradation is rising globally (Symeonakis et al., 2016). The restoration of infertile soils has increasingly been recognized as a vital option for achieving the food security (Mekuria et al., 2016). Furthermore, the sequestration of carbon in soil is essential for the enhancement of soil quality (Körschens et al., 2014; Zhang and Ok, 2014; Bruun et al., 2015). Thus, the development of innovative amendments that enrich carbon content and ameliorate the infertile soils is necessary. Some experts found that the application of chemical fertilizers alone to achieve high yield has not been successful because the crop response to the applied fertilizer depended on soil organic matter (Ojeniyi, 2012).

Degraded land covers approximately 24 % of the global land area and the soil organic carbon (SOC) stocks have decreased to 41 % in tropical regions (FAO and ITPS, 2015). Apart from the high capital outlay of inorganic fertilizer, such as surface and soil degradation and long-term chemical fertilization caused soil physical quality degradation such soil is also prone to acidification (Ogbodo, 2013). Soils of Southeastern Nigeria are poor in their native availability of nutrients, low in organic matter content (usually <1 %) and, hence are structurally degraded (Obalum et al., 2012; Mbagwu, 1989). Soil fertility depletion in small holder farm is the fundamental cause of declining per capita food production (Sanchez et al., 1996). Agbede and Kalu opined that Nigerian farmer's access to fertilizer in vegetable growing season is limited by fund (Agbede and Kalu, 1995). The small holder farmers in Abakaliki are seriously faced with the problems of scarcity and late distribution of fertilizer and conservation methods which in turn militates against optimum productivity (Egwu, 2015). In the face of these challenges, there is a need for a cheaper alternative, and environmentally friendly fertilizer to small holder and commercial farmers for sustainable agricultural productivity in the region. Biochar is a solid material produced by thermochemical conversion of biomass including agricultural waste, animal manure and industrial wood by-products in an oxygen-limited environment (Lehmann and Joseph, 2015). It has an aromatic structure that makes it stable and highly resistant to chemical and biological degradation in soil (Atkinson et al., 2010). Biochar is a C-rich material and has drawn the attention of many researchers owing to its potential application for long-term C sequestration and climate change mitigation (Atkinson et al., 2010; Cayuela et al., 2014). In addition, biochar is increasingly being tested as an organic soil amendment with the aim to improve soil physical, chemical, biological properties, and crop productivity (Kauffman et al., 2014). Most agricultural soils degrade as a result of continuous cropping leading to organic matter and nutrient losses, erosion, and compaction depending on climatic conditions (Githinji, 2014).

Studies on biomass pyrolysis have shown that higher temperature decreases biochar yield and induces changes in biochar structure, pH, volatile matter content and recalcitrance (Zhao et al., 2013; Al-Wabel et al., 2013). Soil chemical Properties such as C and N content, cation exchange

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capacity (CEC), ash and mineral content are also influenced by feedstock (Zhao et al., 2013). The majority of biochars made from straw of different crops have an alkaline pH, and both incubation and field studies have demonstrated that application of alkaline biochar is effective in altering soil pH scale while enhancing soil fertility status by increasing soil nutrients such as K and Mg (Ameloot et al., 2013). Although some studies have documented that microorganisms may use the labile C and N of biochar for their functioning (Woo et al., 2016).

Cucumber (*Cucumis sativus* L.) is a tropical vegetable that grows in warm temperate and cool tropical area. According to a study, cucumber does well with temperature range of 18 and 30°C with growth reduction occurring at temperature below 16°C and above 30°C (De luca et al., 2006). Recently, interest in the production of cucumber by farmers in Abalaliki, South east Nigeria has increased. The increased interest in cucumber production was due to increased demand and consumption of the vegetable in the study area as a result of increase in population arising from the presence of a new Federal University and production factories in the area.

There is urgent need for long-term studies on biochar in field trials to better understand biochar effects and to investigate its behavior in different soil types under varying climatic settings thereby providing a framework information about their potential in improving soil quality and increasing crop productivity, as well as its resultant associated risks (if any). More so, adequate care should be taken on the amount and type of biochar added to the soil for restoring degraded soils (Mekuria and Noble, 2012).

Studies done on biochar effects on Nigerian soils are very few and sparsely attempted and none have tried to narrow it down and investigate the effect of *Tectona grandis* biochar tree species on soil physico-chemical properties and yield of cucumber in the study area. Present review of available literature of biochar in Nigeria shows that nearly all the biochar research was potted/greenhouse experiments (Fagbenro et al., 2015; Onwuka et al., 2015). A group researcher focused on the effect of biochar on soil properties and organic carbon sink in degraded soil of southern guinea savanna zone, Nigeria while other researchers explored the influence of biochar and crop yield on growth and yield of Tomato (*Lycopersicum esculentus* Mill) in Jos, North central Nigeria (Ndor et al., 2015; Yilangai et al., 2014).

Preceding studies assessing biochar impact on soil properties were conducted in controlled environments (Devereux et al., 2012; Castellini et al., 2015; Głą¸ et al., 2016). Nevertheless, there are some important questions considering the advantage of biochar application as soil amendment could be achieved under field conditions.

Therefore, testing across a broad spectrum of soil-crop combinations, biochar sources, different rates of application and different management aspects are crucial before large scale application can be advocated either for SOC sequestration or as a soil amendment. Therefore, the present study was conducted to determine the impacts of different rates of *Tectona grandis* biochar on selected soil physico-chemical properties and yield of cucumber in Highly-weathered Nitisol of Abakaliki, Southeastern Nigeria

2. MATERIALS AND METHODS

2.1 Experimental site

The experiment was carried out at the Faculty of Agriculture and Natural Resource Management Teaching and Research Farm, Ebonyi State University, Abakaliki. The area is located at latitude 06°19¹N and Longitude 08°06¹E and having about 54m elevation above sea level in the derived Savannah of the Southeast agro-ecological zone (Figure 1). The rainfall is fairly distributed throughout the year with minimum annual rainfall of 1,800 mm and maximum of 2,000 mm.

The two-modal pattern of rainfall is experienced between April and July as well as September and November with a break in August. At the start of rainfall, it is aggressive and torrential lasting for 1 to 2 hours (Okonkwo and Ogu, 2002). The greatest extent of relative humidity is 80 % and occurs in the rainy season, while the lowest (60 %) is obtained in the dry season (ODNRI, 1989). The lowest temperature is 27°C while the highest temperature is 31°C, which is experienced during dry season. The dry season intersects with the period of high evapotranspiration and high temperature regime (Ezeaku, 2006).

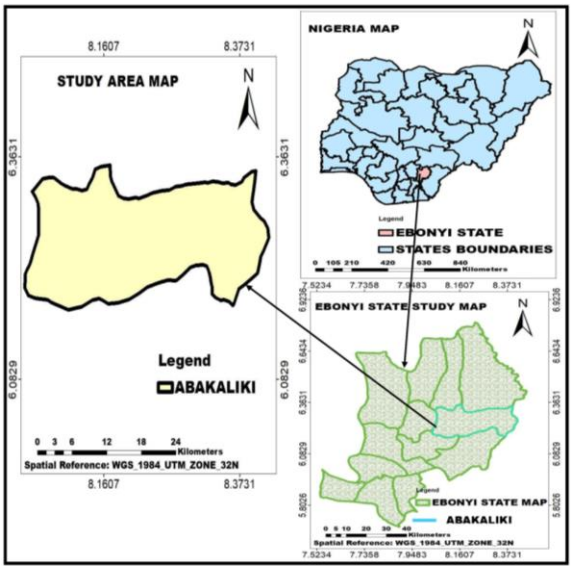

Figure 1: Map OF Nigeria and Ebonyi state showing the location of study area

2.2 Soil and Geology

Larger fraction of the land surface is undulating to undulating plains. The Abakaliki area is underlain by sedimentary rock derived from successive marine deposit from cretaceous and tertiary period, which consists of olive brown shales, fine-grained sand stones and mudstones. The underlying geological material is Shale formation with sand intrusions locally classified as the "ASU River" group (Ukaegbu and Akpabio, 2009).

2.3 Preparation of the biochar and application

Biochar used in the experiment was obtained from a local commercial charcoal producer at Azugwu, Abakaliki, Nigeria who uses hardwood (*Tectona grandis)* in traditional kilns to produce charcoal for domestic use. The temperature inside the kiln was monitored with a thermocouple and had an average temperature of 580 °C for 24 h of carbonizing. The biochar was grounded and sieved to 2mm and thoroughly mixed together before application. Afterwards characterization was carried out according to Biochar material test categories and characteristic of the IBI Biochar Standards Version 2.0 (2014) and incorporated at different rates into the soil.

2.4 Experimental design and cultural management

The experiment was a Randomize Complete Block Design (RCBD) with plot sizes measuring 2 m x 2 m replicated four times (Figure 2). A land area measuring 402.5(equivalent to 0.0402 ha) was marked out, slashed, cleared of grasses and tilled. The field was divided into five blocks with each block having four experimental units giving a total of 20 plots. The experimental units were differentiated from each other by 1m alleys, biochar was applied and allow to stay for 6 months of waiting period before planting for proper mineralization of the biochar.

A test crop Cucumber (*Cucumis sativus* L.) was planted at a spacing of 30 cm x 50 cm inter and intra-row at three Cucumber per hill of 1.5cm soil depth. Thinning to two seedlings per hill was done at two week after planting. The experimental plot was left weed free throughout the study period through periodic manual weeding. Different rates of *Tectona grandis* constitute. They were treatments which are T_1 – No application of biochar (control), T_2 – 2.1 t ha^{-1}, T_3 – 3.4 t ha^{-1}, T_4 –4.7 t ha^{-1}, T_5 – 6.0 t ha^{-1}

2.5 Soil sampling and agronomic data

Soil sample were collected from ten observational points in the experimental site at a depth of 0 - 20 cm using soil auger, and composited. Two undisturbed core soil sample was collected at each plot to determine soil bulk density. At harvest three soil samples were collected from all the plots for physico-chemical analyses to determine the changes that occurred due to treatments application. The agronomic data collected at maturity included Day to 50% Germination count, Days to 50% flowering, vine length, number of fruits, fruit length and yield.

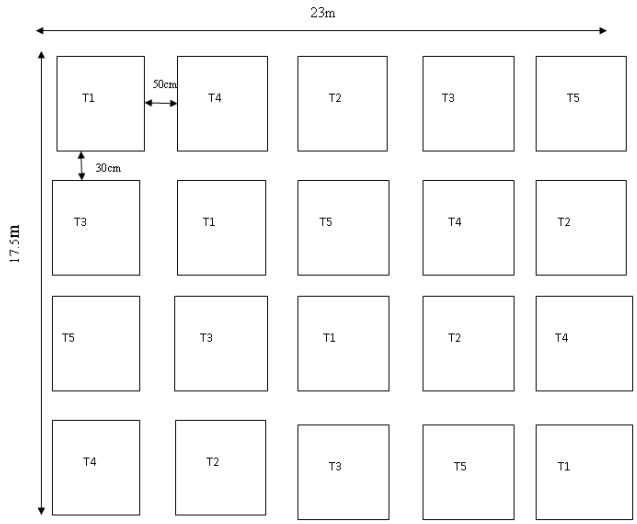

Figure 2: Experimental layout

2.6 Determination of yield parameters

Harvesting was done at maturity in 8 weeks after planting by manually plucking method. nine plants were selected per plot-based on visual evaluation and tagged. The harvested cucumbers were washed in water to remove any traces of sand and dirt and weighed fresh with the aid of a weighing balance. The vine length and fruit length were measured by using meter rule.

2.7 Laboratory analysis

Saturated hydraulic conductivity and volumetric water content were determined using the method described by (Klute, 1986). Bulk density (Bd) was determined as described (Blake and Hartge, 1986). The pre and post-harvest soil samples were air-dried and sieved with 2 mm sieve, and analysis done using the soil fractions less than 2 mm. Soil pH was measured in a 1:2.5 (water) suspensions. The soil organic carbon (SOC) was determined as described (Nelson and Sommers,1982). The total nitrogen was determined by the method described (Bremer and Mulvancy, 1982).

Exchangeable bases (K+, Ca^{2}+, Mg^{2}+ and Na+) were determined by the method of Thomas while effective cation exchange capacity (ECEC) was obtained by summation ECEC = TEB + TEA(where ECEC = effective cation exchange capacity, TEB = total exchangeable bases and TEA = total exchangeable acidity) (Thomas, 1982). Available phosphorus (P) was measured by the Bray II method (Bray and Kurtz, 1945). Particle size distribution was carried out by hydrometer method (Clayton and Tillers, 1979). Total porosity (TP) was calculated from soil bulk density value with an assumed particle density of 2.65 g cm-3 as follows:

TP $[1-(B_D/P_D] \times 100$

Where

Pd = Particle density (2. 65gcm^3)

Bd =Bulk density.

TP=Total porosity

2.8 Data analysis

Statistical analysis of collected data was achieved using SPSS statistical package (version 20). Significant treatment means were separated and compared using Fishers Least Significant Difference (F-LSD) according to a study, (Steel and Torrie, 1980). All inferences were made at 5% probability level.

3. Results

3.1 Chemical content before application

The initial soil properties presented in Table 1 shows that the soil is strongly acidic with a pH value of 4.61 and the available phosphorous (P) value was relatively high with a value of 20.6 $mgkg^{-1}$. The properties of *Tectona grandis* wood ash before application showed higher concentrations of nutrients in the ash (Table 2). The pH of the ash is neutral (7.3) and very high in available P (17.62 mgkg-1). Thus, the ash is relatively rich in the plant chemical elements.

Table 1: Initial Soil Properties (Pre-Sample)

Parameters	Units (soil)	Values
Sand	60.0	%
Silt	26.40	%
Clay	13.60	%
pH	4.61	
Phosphorus	20.6	$mgkg^{-1}$
Nitrogen	0.084	%
Organic carbon	0.99	%
Calcium	4.10	$cmolkg^{-1}$
Magnesium	1.20	$cmolkg^{-1}$
Potassium	0.248	$cmolkg^{-1}$
Sodium	0.249	$cmolkg^{-1}$
Exchangeable acidity	1.16	$cmolkg^{-1}$
Cation exchangeable acidity	6.96	$cmolkg^{-1}$
Base saturation	83.29	%

Table 2: Biochar properties before application

Parameters	Values	Unites
pH	7.3	
Phosphorus	17.62	$mgkg^{-1}$
Nitrogen	0.73	%
Organic Carbon	59.0	%
Calcium	0.55	$cmolkg^{-1}$
Magnesium	0.31	$cmolkg^{-1}$
Potassium	4.2	$cmolkg^{-1}$
Sodium	0.69	$cmolkg^{-1}$
Ash Content	18.24	%

4. Effect of Biochar on Physical Properties of the Soil

4.1 Bulk density, total porosity, moisture content and hydraulic conductivity as influenced by application of biochar

Soil Bulk density (Bd) values decreased significantly ($p < 0.05$) in all the plots amended with biochar and showed an increase with the control plots (1.53gcm^3). Among the plot treated with biochar, significant decrease in soil bulk density value was lowest with the plots amended with 2.1 t ha^{-1} of biochar (1.43gcm^3) followed by plots amended with 6 t ha^{-1} of biochar (1.43gcm^3) and 3.4 t ha^{-1} of biochar (1.46 gcm^3). Higher bulk density value was observed with plots amended with 4.7 t ha^{-1} of biochar (1.48gcm^3). Results in table 3 further revealed that application of *Tectona grandis* biochar had no significant effect on moisture content (MC) and total porosity (TP) of the soil (P>0.05), therefore there was no significant different in moisture content and total porosity values among the five treatments. The saturated hydraulic conductivity values decrease significantly ($p < 0.05$) in all the plots amended with biochar (Table 3) with increased in hydraulic conductivity (HC) in soil without biochar amendment (control). The decrease of hydraulic conductivity is more pronounced in the soil amended with 2.1 t ha^{-1} biochar (3.34$cmhr^{-1}$) with highest hydraulic conductivity observed with soil amended with 4.7 t ha^{-1} biochar (16.33$cmhr^{-1}$).

Table 3: Biochar properties before application

Treatments (t ha^{-1})	Bd (gcm^3)	TP (%)	MC (%)	HC (Cm hr^{-1})
0 (C)	1.53	45	14.34	27.41
2.1	1.43	42	13.98	3.34
3.4	1.46	45	14.12	9.50
4.7	1.48	42	14.44	16.33
6.0	1.43	45	13.15	15.48
FLSD (0.05)	0.04	NS	NS	2.08

C= Control, Bd= Bulk Density, TP= Total Porosity, MC= Moisture Content, HC= Hydraulic Conductivity, NS=Not Significant

4.2 Chemical properties of the soil, exchangeable bases and effective cation exchange capacity (ECEC)

Table 4 shows the effect of biochar application on soil chemical properties. Application of biochar significantly increased ($p<0.05$) concentrations of pH, available phosphorus (P), total nitrogen (TN) and organic carbon (OC) than the soils without biochar amendment. Based on landon pH rating, the soils show neutral acidic in all the plots amended with biochar with pH

values that ranged from 6.55 to 6.85 compared to the control plots that shows very strongly acidic with a pH value of 4.77 (Landon, 1991). Biochar applied at 4.7 t ha^{-1} had the highest values of pH (6.85), available phosphorous (40.20 $mgkg^{-1}$) and total nitrogen (0.112%) among the soils amended with biochar. However, soil amended with 3.4 t ha^{-1} of biochar recorded the highest amount of organic carbon (1.41%) compared to the soils amended with 2.1 t ha^{-1} (1.30%) of biochar, 6.0 t ha^{-1} of biochar (1.30) and 4. 7 t ha^{-1} of biochar (0.97 %.). Plots amended with 0 t ha^{-1} of biochar rate (control) shows a significant decline ($P<0.05$) in the concentration of all the soil chemical properties relative to the plots treated with biochar (Table 4). Available phosphorous was rated high and nitrogen was rated low in both plots amended with biochar and plots without biochar (control) according to the critical level of 10.0 mg kg^{-1} available P and 0.20% N recommended for crop production in ecological zones of Nigeria (Akinrinde and Obigbesan, 2000).

Table 4: Effect of biochar on soil chemical properties

Treatments OC (t ha^{-1})	pH	P ($mgkg^{-1}$)	TN (%)	OC (%)
0 (C)	4.77	20.30	0.056	0.93
2.1	6.55	35.6	0.084	1.30
3.4	6.80	38.10	0.084	1.41
4.7	6.85	40.20	0.112	0.97
6	6.75	25.50	0.098	1.30
FLSD(0.05)	0.89	1.88	0.01	0.34

C= Control, P= Phosphorous, NT= Total Notrogen, Oc= Organic Carbon

Results on table 5 shows significant higher ($P<0.05$) concentrations of Ca, Mg, K, Na, CEC and BS in plots amended with biochar compared to plots without biochar (control), but exchangeable acidity (Ea) of the soil was observed to be significantly higher in plots without biochar amendment relative to the plots with biochar. However, cation exchange capacity (CEC) of the soil was significantly higher ($P<0.05$) in plot amended with 6 t ha^{-1} of biochar (9.14 $cmolkg^{-1}$) followed by plots amended with 2.1 t ha^{-1}, 4.7 t ha^{-1} and 3.4 t ha^{-1} of biochar with their corresponding CEC values of 8.42 $cmolkg^{-1}$, 8.14 $cmolkg^{-1}$ and 7.85 $cmolkg^{-1}$ respectively, but plots without biochar (control) was observed to be significantly lower ($p<0.05$) in CEC with a value of 6.35 $cmolkg^{-1}$.

According to the CEC rating proposed by, all the plots amended with biochar and control plots were generally rated low in CEC in the study area (Landon, 1991). Exchangeable Ca and Mg was rated adequate in all the five treatments according to the critical level of 2.0 $cmolkg^{-1}$ exchangeable Ca and 0.4 $cmolkg^{-1}$ exchangeable Mg as recommended for crop production in ecological zones of Nigeria (Akinrinde and Obigbesan, 2000).

However, exchangeable K was rate inadequate in all the five treatments except plots amended with 6.0 t ha^{-1} of biochar (0.164 $cmolkg^{-1}$) based on the critical level of 0.16-0.20 $cmolkg^{-1}$ exchangeable K suggested by Akinrinde and Obigbesan for crop production in ecological zones of Nigeria (Akinrinde and Obigbesan, 2000). Base saturation (BS) was found to be significantly affected by application of biochar ($P<0.05$) and showing significant higher value with all plots amended with biochar relative to plots without biochar (control). Among the plots treated with biochar, base saturation was found to be significantly higher with plots amended with 6 t ha^{-1} and 3.4 t ha^{-1} of biochar (95 % and 95 %) with control plots having the lowest value of base saturation of 84 %. In general plots amended with biochar had base saturation values that ranged from 91 % to 95 %

5. Effect of Biochar on Agronomic Parameters

5.1 Vine Length of Cucumber at Different Weeks after planting (WAP)

The result presented in Table 6 showed that application of biochar significantly influenced ($P<0.05$) vine length at 2WAP, 6WAP and 8WAP and showed no significant effect ($P>0.05$) at 4WAP. Significant higher values of vine length was observed at 8WAP in all the plots treated with biochar which ranged from 54.56 to 61.64cm compared with plots without biochar (control) with vine length value of 42.24cm.

Among the plots treated with biochar at 8WAP, biochar applied at 4.7 t ha^{-1} significantly produced the highest vine length of 61.64cm followed by plots that received 3.4 t ha^{-1} of biochar (57.59cm) and the lowest with plots that received 2.1 t $ha^{-1}$of biochar (54.56cm). Results in table 6 further revealed that biochar applied at 4.7 t ha^{-1} significantly produced the highest vine length at 2WAP (5.82cm), 6WAP (29.78) and 8WAP (61.64) relative to other biochar rates.

Table 5: Effect of biochar on soil exchangeable bases, Effective cation exchange capacity (ECEC) and base saturation (BS)

Treatments (t ha^{-1})	Ca	Mg	K	Na	Ea	CEC	BS
	($cmolkg^{-1}$)						(%)
0 (C)	3.6	1.60	0.061	0.052	1.04	6.35	84
2.1	5.20	2.40	0.113	0.07	0.64	8.42	92
3.4	5.6	1.60	0.154	0.096	0.40	7.85	95
4.7	4.80	2.40	0.143	0.078	0.72	8.14	91
6	6.40	2.00	0.164	0.096	0.48	9.14	95
FLSD (0.05)	0.71	0.55	0.00	0.01	0.11	0.36	2.44

C= Control

5.2 Day to 50% germination, 50% flowering, fruit length and number of fruits

Results in table 7 shows that application of biochar had significant effect on day to 50% flowering, fruit length, number of fruits and yield of Cucumber and showing significant higher values in plots amended with biochar relative with the control plots. Biochar applied at 4.7 t ha^{-1} showed significant highest ($P<0.05$) values at day to 50% flowering (35%), fruit length (17.20cm) and number of fruits (52.04) among the plots amended with biochar and with the control plots having the lowest values (31%, 13.4cm and 35.48) respectively. However, application of biochar had no significant effect ($P>0.05$) on day to 50% germination, therefore there is no significant different detected among the five treatments.

Weeks After Planting (WAP)

Table 6: Effect of Biochar on Vine Length (cm) of cucumber at weeks after planting

Treatment (t ha^{-1})	2	4	6	8
0 (C)	3.80	11.24	23.30	42.24
2.1	4.10	10.41	21.06	54.56
3.4	5.42	12.48	26.41	58.59
4.7	5.82	14.18	29.78	61.64
6.0	4.14	12.96	20.49	57.21
FLSD (0.05)	0.24	NS	0.16	1.73

C= Control, NS = Not-significant.

5.3 Yield of Cucumber

The cucumber yield as influenced by application of biochar is shown in table 7. Results indicates that application of biochar significantly ($P<0.05$) increased yield of cucumber in all the plots amended with biochar which ranged from 4.70 t ha^{-1} to 7.50 t ha^{-1} relative to the control plots with a yield value of (4.23 t ha^{-1}).

Among Plots amended with biochar, biochar applied at 4.7 t ha^{-1} and 3.4 t ha^{-1}showed to had significantly produced the highest yield of cucumber (7.5 and 7.42) respectively (Figure 3), followed by plots that received 6.0 t ha^{-1} of biochar rate (6.63) with the lowest yield recorded with plots amended with 2.1 t ha^{-1}(4.70). Comparing the yield of cucumber between the plots amended with biochar and the plots without biochar, it was observe that plots without biochar (control) significantly produced the lowest yield (4.23) and plots amended with biochar on average produced the highest yield of cucumber with a value of 6.56.

Table 7: Effect of Biochar at day to 50% germination, day to 50% flowering, fruit length, number of fruits and yield of Cucumber

Treatment (t ha^{-1})	Day to 50% Germination	Day to 50% Flowering	Fruit length (cm)	Number of fruit	Yield (t ha^{-1})
0 (C)	3.00	31	13.4	35.48	4.23
2.1	4.33	33	15.60	47.74	4.70
3.4	4.00	33	16.30	51.85	7.42
4.7	4.44	35	17.20	52.04	7.5
6.0	4.1	34	14.80	37.43	6.63
FLSD (0.05)	NS	0.29	0.34	13.71	1.31

C= Control, NS= Not significant

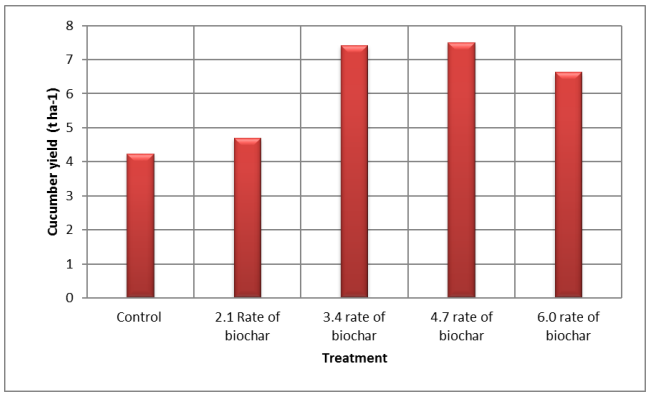

Figure 3: Influence of different rates of biochar on the yield of cucumber

6. Discussion

In tropical African soils, the use of synthetic fertilizer has not been sustainable due to its induced soil acidity and nutrient imbalance (Agbede et al., 2017). In the present study, the bulk density of the control plots was significantly higher ($P<0.05$) compared to the bulk density of the biochar treated plots. A number of studies at both the field and laboratory scale, have reported that manure addition reduces the soil bulk density (Ota et al., 2018a; Are et al., 2012). For instance, research conducted by Ojeniyi et al. (2013) at Akure, Nigeria, on sandy loam soil found that 5 t ha^{-1} of poultry manure reduced the soil bulk density by 13.9 % (Ojeniyi et al., 2013). Study carried out at Ebonyi state, Southeastern Nigeria on different land use types showed that addition of organic matter through litter fall significantly reduced the bulk density of the soil in forest lands compare to cultivated and grazing areas (Ota et al., 2018b). In India, a group researcher reported a 7.8 % reduction in the soil bulk density in an experiment involving biochar-amended soils (Mankasingh et al., 2011). These relationships between biochar application and physical properties of soil ware also observed by Herath et al. (2013) and similar effects were reported in laboratory and field-scale experiments (Herath et al., 2013; Mukherjee and Lal, 2013). They confirmed that improved physical quality of biochar-amended soil is correlated with biochar rates. The decrease in bulk density of the biochar-amended soils could also be ascribed to changes in soil structure and alteration of soil aggregate sizes (Jien and Wang, 2013). Total porosity and moisture content were not significantly affected ($P>0.05$) by application of biochar and shows no significant difference among plots treated with biochar and control. This may be attributed to the internal orientation of particles forming aggregates and biochar, due to its recalcitrant condition which may have a long-term potential impact on the functioning of soils by improving their hydraulic properties, moisture and total porosity and as a source of carbon sequestration (Spokas et al., 2012; Verheijen et al., 2010).

The results of the study have shown that application of biochar significantly reduced ($P<0.05$) hydraulic conductivity of the soil in all the plots amended with biochar compared to plots without biochar (control). It has been observed that biochar particles, when added to soils, reduce the saturated hydraulic conductivity due to the formation of narrower pores (Yargicoglu et al., 2015). Hydraulic properties depend on texture, structure and pore characteristics (Hartge and Horn, 2016). Biochar addition furthermore alters the pore size distribution as well as the hydraulic conductivity but the intensity depends also on the rates of application of biochar. Biochar addition enhances physical and hydraulic soil properties by adding porous substances to the soil, modifying water retention, total porosity and pore structure (Burrell et al., 2016; Novak et al., 2012).

The significant increase in chemical, exchangeable bases and base saturation (pH, N, P, K, Ca, Na, Mg, CEC and BS) values of the soil in response to application of biochar was consistent with the plots amended with biochar relatives to untreated plots (Table 5). Notably, biochar applied at 3.4 t ha^{-1} in the present study had similar Mg to untreated soils (control). The mechanism responsible for increase in soil pH was likely due to ion exchange reactions which occur when terminal OH− of Al3+ or Fe2+ hydroxyl oxides are replaced by organic anions which are decomposition products of biochar manure (Duruigbo et al., 2007; Dikinya and Mufwanzala, 2010). The ability of organic carbon to increase soil pH could also have been due to the presence of basic cations contained in the biochar. A group researcher reported that such basic cations are released upon microbial decarboxylation (Duruigbo et al., 2007). In a greenhouse experiment, indicates an increase in soil pH with the addition of 15, 30, 75, 150, and 225 Mg ha_1 biochar in loamy sand texture (Alburquerque et al., 2014). Application of biochar in the present study has shown an increase in soil pH from 4.77 in control plots to an overall average of 5.24 in biochar treated plots. Incubation studies have also indicated that biochar application is effective in altering soil pH, and particularly favorable for use in acidic soils for increasing pH (Prendergast-Miller et al., 2014). The carboxylate groups found in black carbon provide cation exchange capacity (CEC), increase the organic carbon, and are the primary source of biochar high nutrient retention ability (Glaser et al., 2001). Several studies also showed that soils biochar additions improve cation exchange capacity (CEC) enhancing the bounding nutrient-soil conditions and preventing the leachate of nutrients to surface waters and deeper soil regions (Liang et al., 2006; Verheijen et al., 2010; Zornoza et al., 2016). Significant higher CEC in all the biochar amended plots compared to untreated plots (control) in the present study could be also informed due to biochar porous structure, large surface area and negative surface charge (Bird et al., 2008; Downie et al., 2009). Increase in the soil's cation exchange capacity allows for the retention of nutrients. Other studies have found that biochar addition may increase pH producing a liming effect and reduce the risk of some metal toxicity (i.e. aluminum) (Verheijen et al., 2010). Unexpectedly, the physico-chemical properties of the soil in the present study have showed inconsistent increase with increased in biochar application rate. This is not in consonance with the study conducted by who reported that total carbon, TC (which is mostly organic) of the amendments increased as the rate of biochar increased, because biochar is a source of organic carbon (Glaser et al., 2001).

As the biochar components decomposed, nutrients were released to the soil and hence, our findings show that biochar applied at the rates of 4.7 t ha^{-1}, significantly increased soil pH, Available phosphorous and total nitrogen. Significant increase in other chemical and exchangeable base in the study could also be linked to the fact that Biochar absorbs leachate generated during the process, with the leachate, biochar also absorbs organic matter and nutrients, resulting in increased concentrations of water-extractable organic carbon, total soluble nitrogen, plant-available phosphorus and plant-available potassium, therefore increasing nutrient retention capability of the soil (Jia et al., 2015). A result showed that Exchangeable acidity (Ea) was observed to be higher in plots without biochar amendment (control) compared to biochar treated plots. Findings has showed that biochar releases basic cations and high carbonate contents which can neutralize the acidity and increase the pH of the soil (Chintala et al., 2014a). Similar to the findings of this study, acidic soils showed greater pH response to biochar than alkaline soils (Biederman and Harpole, 2013).

Application of biochar has significantly increased ($P<0.05$) agronomic parameters (day to 50% flowering, fruits length, number of fruit and yield) in all the plots amended with biochar relative to untreated plots. Lehmann and Rondon have reported that most of the results of deliberate biochar additions to soil have also showed increasing crop yields with increasing additions up to very high loadings of 140 Mg C ha^{-1} (Lehmann and Rondon, 2006). Although day to 50% germination was not significantly influenced ($p>0.05$) by application of biochar, lack of statistical differences in our study among plots treated with biochar and plots without biochar application could be attributed to delayed N mineralization and insufficient application rate to cause detectable changes in day to 50% germination. The results from our study supports the findings of who suggested that the influence of biochar on soil physical properties and growth performance could be related to specific biochar-type, rate and/or site-specific characteristics (Peng et al., 2011; George et al., 2012). Significant increase of yield parameters in all the amended plots relative to untreated plots (control) is generally influenced by physical and chemical characteristics of soil organic carbon. Biochar may serve as a C source for microorganisms and this may increase the biotic mineralization of easily degradable labile C in the biochar (Farrell et al., 2013). Nevertheless, due to the abundance of thermodynamically stable aromatic organic compounds, biochars are considered to be microbially stable and protected from decomposition (Abujabhah et al., 2016).

Results of the present study (Figure 3) has proved that biochar applied at 4.7 t ha^{-1} rate among the plots treated with biochar and the control plots performed better by significantly producing the highest values for all the agronomic parameters studied (day to 50% flowering, fruits length, number of fruit and yield) followed by biochar applied at 3.4 t ha^{-1} rates and lowest cucumber yield was observed with untreated plots (control). This could be attributed to the fact that biochar applied at 4.7 t ha^{-1} rate is sufficient to cause detectable change to produce highest cucumber yield and other agronomic parameters. Studies have also showed that biochar application to soils alone or in combination with either organic or inorganic fertilizer has been reported to have a pronounced effect on plant growth and yield (Dou et al., 2012; Chan et al., 2007). It is worthy to

mention that the increased agronomic parameters recorded with addition of biochar in the present study are totally in variance with the findings (Schultz et al., 2014). In their investigation, they found a negative effect on growth and yield of oat plant with application of biochar on soil, though it was greenhouse experiment and needed field research to negate or affirm their findings. In furtherance, it was observed that control plots had the lowest values and performed low for all the agronomic parameters. This could be linked to the fact that control plot was not amended with biochar and biochar has the potential to improve soil physical and chemical properties to restore a favorable environment for plant root growth, root penetration, and nutrient and water uptake (Githinji, 2014).

7. Conclusion

The effects of biochar application varied strongly according to the rates of application. The results indicated that different rates of biochar application added as soil amendment had the potential of improving soil quality and boosting productivity of cucumber in a highly weathered Nitisol of Abakaliki Southeastern, Nigeria relative to untreated plots. Overall results suggested that amending soil with *Tectona grandis* biochar significantly increase soil physical properties (bulk density and hydraulic conductivity), chemical and exchangeable bases (pH, N, P, K, Ca, Na, Mg, CEC and BS) under field conditions, but did not result in any improvements or significant effect on total porosity (TP), moisture content (MC), vine length (4WAP) and day to 50% germination. Despite some limitations in our study, such as using only one woody biochar and short term analysis, our study is among the few studies which evaluated the impact of *Tectona grandis* biochar treatment under field conditions and at different rates with cucumber in Abakaliki. Remarkably, application of biochar at 4.7 t ha^{-1} resulted to the highest improvement in all the agronomic parameter in the present study (table 7). However, biochar applied at 3.4 t ha^{-1} had the highest agronomic efficiency of 96.2 % against biochar applied at 4.7 t ha^{-1} with agronomic efficiency of 69.6 %. Our study highlights that the benefits to improve soil physical, chemical and agronomic parameters which have been reported in this finding may not be achieved by using a relatively low biochar application rate (2.1 t ha^{-1}) but realistic application rate of 3.4 t ha^{-1} and $^{4.7}$ t ha^{-1} in field conditions in Abakaliki southeastern ecological zone of Nigeria is highly recommended. Therefore, further study is needed to assessing the potential of biochar and aged biochar to alleviate highly-weathered and acid soils for achieving crop productivity.

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Declaration of Submission and Verification

We confirm that this work is our original work and has not been published elsewhere, nor currently under consideration for publication in another journal

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