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Amelioration of a degraded ultisol with hardwood biochar: Effects on soil physico-chemical properties and yield of cucumber (*Cucumis sativus L)*

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A study was conducted in two consecutive cropping seasons to assess the effect of biochar on soil properties and yield of cucumber (*Cucumis sativus* L) in an intensive cucumber–maize rotation based system of Abakaliki, Southeastern Nigeria. Five rates of hardwood biochar (0, 2.5, 3.75, 5 and 6.25 t ha^{-1}) were used for the study. The study was laid out as a randomized complete block design (RCBD) with five treatments and four replications. Data were collected from both soil and plant parameters. Soil samples (0 to 20 cm) were collected before and at harvest from different plots for soil chemical analyses. Results obtained from the study showed significant ($P<0.05$) improvement in soil properties. Bulk density (BD) was significantly ($p<0.05$) decreased in biochar amended plots. Total nitrogen (N), available phosphorus (P), organic carbon (C), pH and exchangeable bases (K^+, Ca^{2+}, Mg^{2+} and Na^+) were significantly ($p<0.05$) higher in biochar amended plots relative to the control. Biochar application significantly ($p<0.05$) increased vine length, number of fruits, fruit length and yield of cucumber compared to the control. On average, 6.25 t ha^{-1} rate of biochar application gave the highest improvement in soil properties while highest increase in yield and other agronomic parameters were observed in 5 t ha^{-1} rate of application. The study recommended 5 t ha^{-1} as the maximum rate of biochar application in the study area. Our results indicated that biochar application could be a possible way of improving soil properties and native soil carbon in the degraded ultisols and intensive cropping systems.

Key words: Mineral fertilizer, organic inputs, small holder farms, soil productivity, sustainable agriculture.

INTRODUCTION

Unprecedented global population growth, the expansion of agricultural frontier and other human activities encroaching on fragile ecosystems in many parts of the world, especially in Sub-Saharan Africa, has necessitated the urgent need for increased and sustainable agricultural production. Agriculture is the main source of livelihood

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and income for two-third of Africa’s population (Ditto, 2013). Imhoff et al. (2004) showed that agricultural production must increase significantly to meet the needs of a growing global population with increased per capita consumption of food, fibre, building materials and fuel. Most small holder farms have soils depleted of nutrients and soil organic carbon (SOC), following years of nutrient removal in crop harvest with minimal return of crop nutrients through mineral fertilizer or organic inputs (Smalling et al., 1993). Using burnt and unburnt rice husk dust as soil amendment, Njoku and Mbah (2012) reported improved soil properties and increased maize grain yield.

Biochar is a charcoal (carbon-rich solid material) produced under high temperatures (300 to 500°C) through the process of pyrolysis using crop residues, animal manure, or any type of organic material (Bracmort, 2010). The two main methods of pyrolysis are “fast” pyrolysis (heating of biomass in the absence of oxygen, Chan et al. (2007) and “slow” pyrolysis (by natural burning or by the combustion of biomass under oxygen-limited conditions, Sohi et al. (2009). Fast pyrolysis yields 60% bio-oil, 20% biochar, and 20% syngas and can be done in seconds, whereas slow pyrolysis can be optimized to produce substantially more char (~50%), but takes on the order of hours to complete (Odesola and Owoseni, 2010). Lehmann and Joseph (2012) have distinguished the term biochar from charcoal in that it is charred organic matter that is applied to soil not only to improve soil properties but also to promote soil remediation or other environmental services while the charcoal is used as fuel or source of heat, as a filter, as a reductant in iron-making or as a colouring agent in industry or art. Researches on biochar are expanding rapidly not only because of its potential for carbon sequestration (Sohi and Shackley, 2009) but also for its several co-benefits as soil amendment, such as increase in crop yield (Akca and Namli, 2015), potential as a technology for immobilizing pollutants (Herath et al., 2015) and increasing soil fertility and nutrient retention in soils. Though previous researchers have really explored the potentials of biochar as soil amendments for agricultural production and improvement of soil quality (Ndor et al., 2015), research on accurate rate of biochar application on a degraded Ultisol and other soil types for specific arable crops is scanty and rather proceeding slowly. Furthermore, biochar’s effect is soil type dependent (Nelissen et al., 2015) and also, biochar effects on soil aggregation is dependent on soil and biochar types (Herath et al., 2013). Moreover, biochar properties depend both on feedstock and production conditions, through which biochar’s impact on soil properties is expected to vary (Ronsse et al., 2013).

Studies done on biochar effects on Nigerian soils are very few and scanty. Current review of available literature of biochar in Nigeria indicates that nearly all the biochar research were potted/greenhouse experiments (Fagbenro et al., 2015; Onwuka et al., 2015). Ndor et al. (2015) focused on the effect of biochar on soil properties and organic carbon sink in degraded soil of southern guinea savanna zone, Nigeria while Yilangai et al. (2014) investigated the effect of biochar and crop yield on growth and yield of Tomato (*Lycopersicum esculentus* Mill) in Jos, North central Nigeria. 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). Many of the short-term effects of biochar on plant growth and soil behavior reported from laboratory studies were not observed in the field emphasizing the need for long term field trials to help inform agronomic management decisions involving biochar (Jones et al., 2012). 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).

Soils of Southeastern Nigeria are poor in their native availability of nutrients (Mbagwu, 1989), low in organic matter content (usually <1%) and, hence are structurally degraded (Obalum et al., 2012). Soil fertility depletion in small holder farm is the fundamental cause of declining per capita food production (Sanchez et al., 1996). Agbede and Kalu (1995) opined that Nigerian farmers’ access to fertilizer in vegetable growing season is limited by fund, thus the Abakaliki small holder farmers are seriously faced with the problems of scarcity and late distribution which in turn militates against optimum productivity. In the face of these challenges, there is a need for cheaper alternative which is environmentally friendly that can make fertilizer more available to small holder farmers for sustainable agricultural productivity.

Cucumber (*Cucumis sativus* L.) is a tropical vegetable that grows in warm temperate and cool tropical area. According to De luca et al. (2006), cucumber does well with temperature range of 18 and 30°C with growth reduction occurring at temperature below 16°C and above 30°C. Recently, interest in the production of cucumber by small holder 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. However, the use of biochar as an amendment has not been really explored in the study area. Thus, published articles/information on how various biochar types affect plant growth and crop yield specifically in the production of cucumber in different soil types is not available in the study area and still proceeding rather slowly.

Based on these assumptions we hypothesized that soil biochar amendment in a cucumber (*Cucumis sativus* L) crop could:

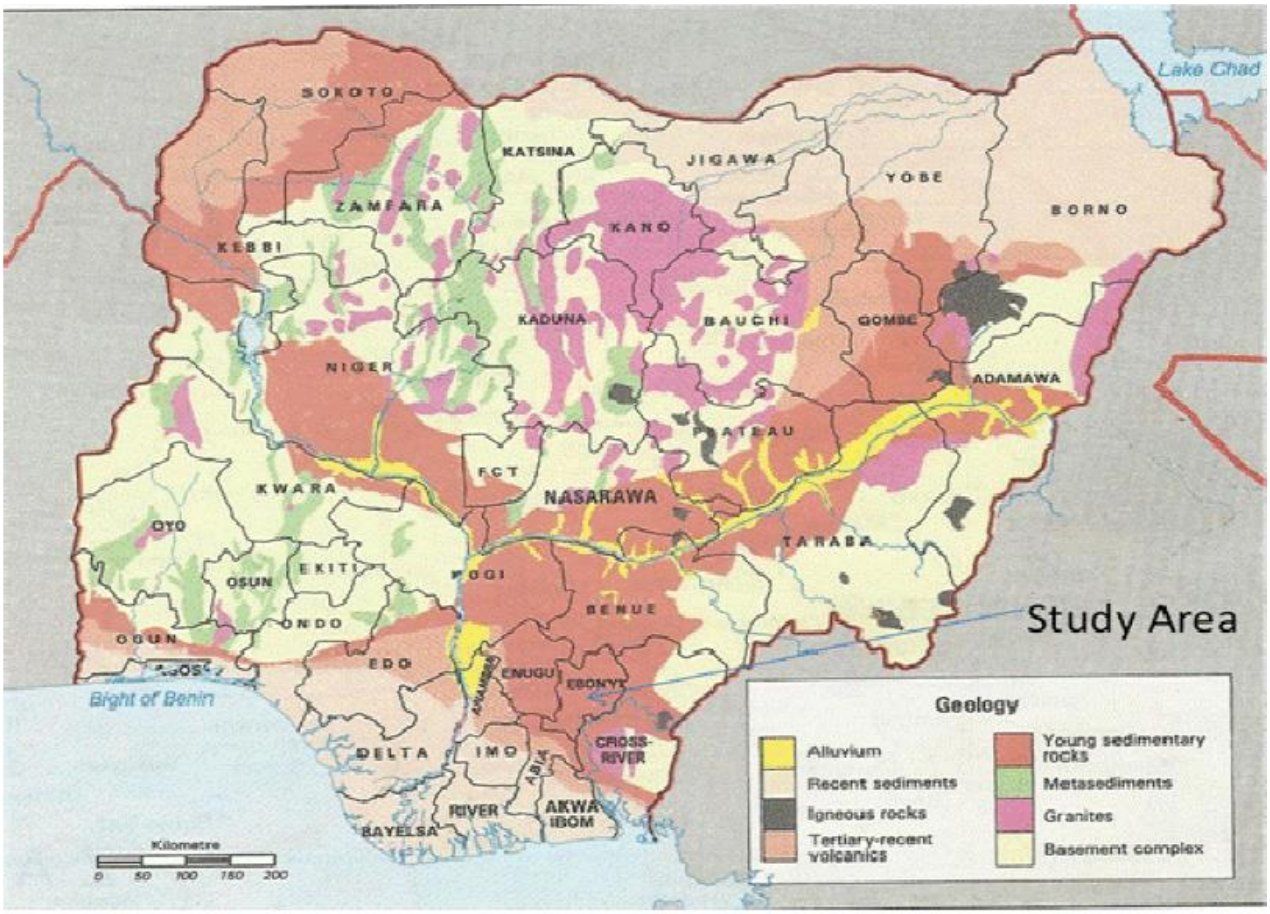

Figure 1. Geologic map of Nigeria showing the location of study area (Balogun, 2000).

i) Improve soil physical quality through decreasing soil bulk density and increasing porosity,
ii) Enhance soil properties and carbon (C) sequestration potential also in a short-term crop;
iii) Improve soil nutrient balance in a degraded soil;
iv) Improve quality and crop yield.

The study will also recommend appropriate rate of biochar for use in cucumber (*Cucumissativus L*) production in the study area for sustainable agricultural productivity.

MATERIALS AND METHODS

Study area

This research was carried out during the 2012 and 2013 cropping seasons in the Teaching and Research Farm of Faculty of Agriculture and Natural Resources Management, Ebonyi State University, Abakaliki, Nigeria (Figure 1). Abakaliki (longitude 08° 65´E, latitude 06° 04´N, temperature 27 - 31°C, rainfall 1700 to 2000 mm, relative humidity 60 to 80%) experiences bimodal pattern of rainfall (April to July and September to November) with short spell in August called "August break". The relative humidity is high during rainy season reaching 80% (Overseas Development of Natural Resources Institute, ODNRI, 1989) and declines to 65% in dry season. The underlying geological material is Shale formation with sand intrusions locally classified as the 'ASU River' group. The soil is hydromorphic and belongs to the order Ultisol and classified as TypicHaplustult (Federal Department of Agricultural Land Resources (FDALR), 1985). Farming is the major activity of people of the area. Land uses include low land traditional rice farming; multiple (annual) cropping (cassava, plantain, cocoyam, maize, vegetables, pepper, melon seed and beans); citrus and oil palm plantations, herbaceous plants, grasses as bush fallow, and natural forest through the crest to lowlands of the upland-inland continuum (Okolo et al., 2013). The soil is sandy loam with moderate soil organic carbon (OC) content, low in pH and cation exchange capacity (CEC), with dominance of the exchange complex site by calcium and magnesium (Table 1).

Preparation of the biochar

The biochar of four different species of hard wood (Iroko: *Chlorophora excelsa*, Obeche: *Triplochiton sleroxylon*, Oil palm: *Elaeis guineensis* and Gmelina: *Gmelina arborea*) bought from a local distributor (pyrolysed at 350°C for 3 h) was manually crushed to particle sizes smaller than 2 mm and thoroughly mixed together. 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.

Table 1. Some properties of the topsoil (0 to 20 cm) and biochar before amendments (pre-planting).

Parameter	Unit	Soil	Biochar
Sand	gkg^{-1}	680	Nd
Silt	“	178	Nd
Clay	“	142	Nd
Bulk density	gcm^{-3}	1.60	Nd
pH (0.01M $CaCl_2$)		5.9	7.5
Exchangeable bases	$cmolkg^{-1}$		
Na^+	0.09	1.81	
K^+	0.10	3.78	
Mg^{2+}	1.70	1.89	
Ca^{2+}	2.10	1.55	
Total nitrogen	gkg^{-1}	0.9	0.88
Available phosphorus	gkg^{-1}	3.78	22.01
Organic carbon	gkg^{-}	10.1	64.24
Ash content	%	Nd	21.0
SSA (Specific surface area)		Nd	0.8

Nd = Not determined.

Field methods/preparations

The site was slashed and cleared of grasses in July, 2012. A total land area measuring 11 by 14 m (0.154 ha) was used for the study. The experiment was laid out as a randomized complete block design (RCBD) with five treatments and replicated four times to form twenty plots. The experimental plots measured 2 m by 2 m with 1 m plot alley. The soil amendment was a thorough mixture of different hardwood biochar (Iroko: *Chlorophora excelsa*, Obeche: *Triplochiton sleroxylon*, Oil palm: *Elaeis guineensis* and Gmelina: *Gmelina arborea*) applied at different rates and these included:

$\mathbf{T_1}$ = Control; $\mathbf{T_2}$ = 1.0 kg/plot; $\mathbf{T_3}$ = 1.5 kg/plot; $\mathbf{T_4}$ = 2.0 kg/plot and $\mathbf{T_5}$ = 2.5 kg/plot (equivalent to 0, 2.5 t/ha, 3.75 t/ha, 5 t/ha and 6.25 t/ha, respectively). The experimental site was cleared, ploughed, harrowed and made into seed beds with traditional hoe. The treatment (hardwood biochar) were crushed and incorporated into the beds at the depth of 0.20 mduring tillage. Cucumber (*Cucumis sativus* L. variety “market more”) was sown at three (3) seeds per hill. The seeds were planted at a distance 30 cm and 50 cm and at a depth of 1.5 cm. The cucumber plants were thinned to two plants per hill ten days after germination. The same procedure was equally carried out in 2013 cropping season at the same experimental site.

Soil sampling and data collection

A composite topsoil sample from ten observational points at a depth of 0 - 20 cm was collected from the experimental site with the aid of soil auger after site clearing for initial soil characteristics. At harvest (end of the study), three soil samples were collected from all the plots for chemical analyses to determine the changes that occurred due to treatments application. Similarly, three core samples were collected from each plot at the end of the study for determination of physical properties. The auger soil samples were composited, air dried and used for determination of pre and post nutrient content of the soil. The agronomic data collected at maturity included vine length, number of fruits, fruit length and yield. At maturity nine plants were selected per plot-based on visual evaluation and tagged. Agronomic data (vine length, fruit length, number of fruits and yield) were collected from the tagged plants. The harvested fruits were weighed with the aid of a simple weighing balance with two decimal places.

Laboratory analysis

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 (soil:0.1 M KCl) suspensions. The soil organic carbon (SOC) was determined by the Walkley and Black method as described by Nelson and Sommers (1982). The total nitrogen was determined by the method described by Bremmer and Mulvancy, (1982). Exchangeable bases (K^+, Ca^{2+}, Mg^{2+} and Na^+) were determined by the method of Thomas (1982) 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). 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). Bulk density was determined using the core method as described Blake and Hartge (1986). Total porosity was calculated from soil bulk density value with an assumed particle density of 2.65 g cm^{-3} as follows:

$$TP = 1 - (BD/PD) \times 100$$

Where TP = Total porosity, BD = Bulk density and PD = Particle density.

Data analysis

Statistical analysis of all the data was performed using GENSTAT 3 7.2 Edition. Significant treatment means was separated and compared using Fisher’s least significant difference (F-LSD) according to Steel and Torrie (1980), and all inferences were made at 5% Levels of probability.

Table 2. Effect of biochar on soil bulk density (gcm^{-3}) and total porosity (%).

Treatment (t ha^{-1})	BD	TP	BD	TP
	2012		2013	
0 (C)	1.50	43	1.53	42
2.5	1.47	45	1.46	45
3.75	1.47	45	1.45	45
5.0	1.46	45	1.44	46
6.25	1.45	45.3	1.44	46
FLSD = 0.05	0.21	NS	0.28	0.12

C=control,BD=Bulk density, TP=Total porosity.

RESULTS

Table 1 showed that the soil has low total nitrogen (g kg^{-1}), medium available phosphorus (mg kg^{-1}) and low organic carbon (g kg^{-1}) according to the ratings of Landon (1991). The soil is moderately acidic (pH 5.9) (USDA-SCS, 1974). Application of biochar significantly ($p<0.05$) decreased soil bulk density and increased the total porosity for the two cropping seasons (Table 2). The biochar material contained high quantity of organic carbon (64.24) prior to application. Bulk density values ranged between 1.50 to 1.45 g cm^{-3} and 1.53 to 1.44 g cm^{-3} in the first and second cropping seasons, respectively. In the first cropping season highest bulk density value of 1.50 g cm^{-3} was observed in the control (C). This value was 2, 2, 3 and 3% higher than the bulk density values in 2.5, 3.75, 5.0 and 6.25 t/ha rate of applications, respectively. The table showed non-significant ($p > 0.05$) increase in soil total porosity (TP) among the amended plots in the first cropping season. However a 5% increase over the control was observed across the treatments. The order of increase in soil total porosity in the second cropping season was 6.25 t/ha = 5 t/ha > 3.75 t/ha > 2.5 t/ha > C.

C = Control, BD = Bulk density, TP = Total porosity, NS = Not significant.

Results of the study in Figures 2 to 5 showed significant ($p < 0.05$) increase in all the soil chemical properties (pH, total nitrogen, organic carbon and available phosphorus) in biochar amended plots compared to the control as shown in their strong R^2 values. Specifically in the first cropping season, organic carbon (OC) (mgkg^{-1}) in control was 6, 41, 42 and 44% lower than OC in 2.5, 3.75, 5.0 and 6.25 t/ha rate of application, respectively. Soil pH with second-order polynomial regression was strongly correlated with biochar (R^2 = 91.2 and 99.7% for 2012 and 2013, respectively; Figure 2) treatments. The order of increase in soil pH was 5.0 t/ha > 6.25 t/ha > 3.75 t/ha > 2.5 t/ha > C in the second cropping season.

The trend of increase in total N (g kg^{-1}) in the first cropping season was 6.25 > 5.0 > 3.75 > 2.5 t/ha > C. In the second cropping season, total N in the control was 33, 33, 83 and 83% lower than in 2.5, 3.75, 5.0 and 6.25 t/ha rate of application, respectively. The highest second-order polynomial regression (R^2 = 97%) was obtained between total nitrogen and biochar in the first year while the second year value was R^2 = 90.3% (Figure 3). Figure 4 show higher OC in the first cropping season compared to the second cropping season. Soil organic carbon was strongly correlated with biochar (R^2 = 82.4% and R^2 = 79.6% for first and second year, respectively) treatments (Figure 4).

There was a remarkable increase in available phosphorus (P) in amended plots relative to the control in both cropping seasons (Figure 5). The order of increase in available P was 6.25 t/ha = 5.0 t/ha > 3.75 t/ha > 2.5 t/ha > C and 6.25 t/ha > 5.0 t/ha > 3.75 t/ha > 2.5 t/ha > C in the first and second cropping seasons, respectively. Second-order polynomial regression analysis showed that available phosphorus in the first year was most associated with biochar (R^2 = 99.8%) treatment more than the second year (R^2 = 99.3%; Figure 5).

Higher exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were observed in the amended plots relative to the control in both cropping seasons (Table 3). Potassium (K^+) and Ca^{2+} ranged between 0.08 to 0.15 and 3.7-5.8 (cmolkg^{-1}), respectively in the first cropping season. In the second cropping season, highest values of K^+ and Ca^{2+} were observed in 6.25 t/h rate of application. The order of increase in Na^+ in the second cropping season was 6.25 > 3.75 > 5.0 > 2.5 t/ha > C. Similarly, ECEC in the second cropping season was 32, 8, 18 and 11% higher than in C, 2.5, 3.75, 5.0 and 6.25 t/ha rate of application, respectively (Table 3).

Results of the study (Table 4) showed significantly ($p<0.05$) higher fruit and vine length in amended plots relative to the control. Fruit length was lower in the first than in the second cropping season. In both seasons, highest fruit length (17.1 and 17.2 cm) were observed in 5.0 t/ha rate of application. Similarly, higher number of fruits was observed in the amended plots relative to the control. The highest number of fruits (22 and 25) was observed in 5.0 t/ha rate of application in the first and second cropping seasons. The order of increase in the number of harvested fruits in the second cropping season

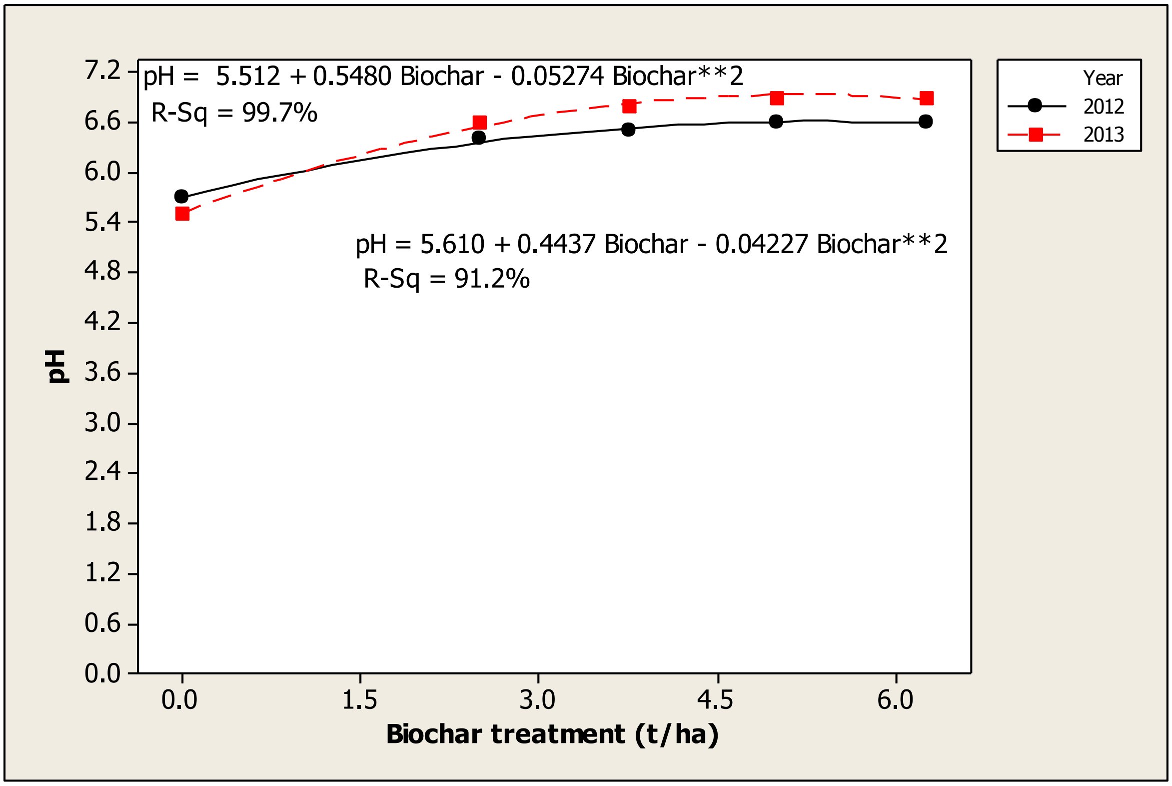

Figure 2. Second-order polynomial regression between biochar treatment and soil pH for the two seasons.

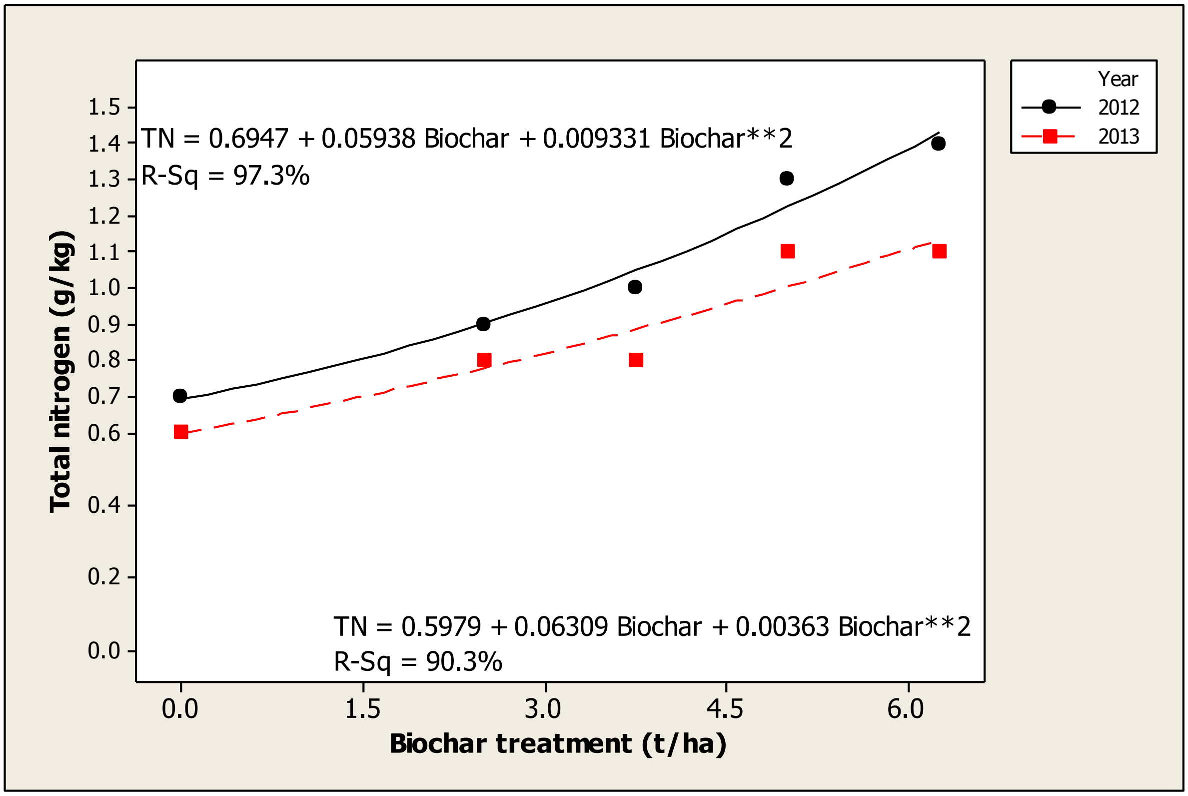

Figure 3. Second-order polynomial regression between biochar treatment and total nitrogen for the two seasons.

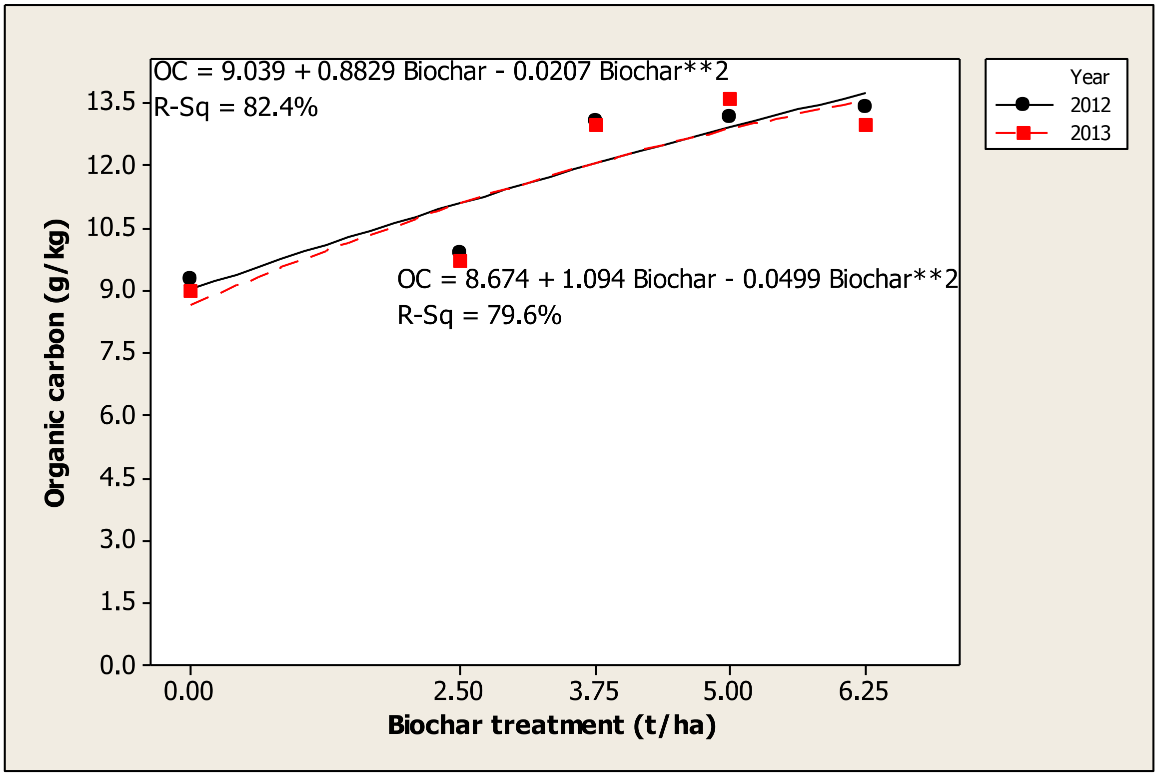

Figure 4. Second-order polynomial regression between biochar treatment and organic carbon for the two seasons.

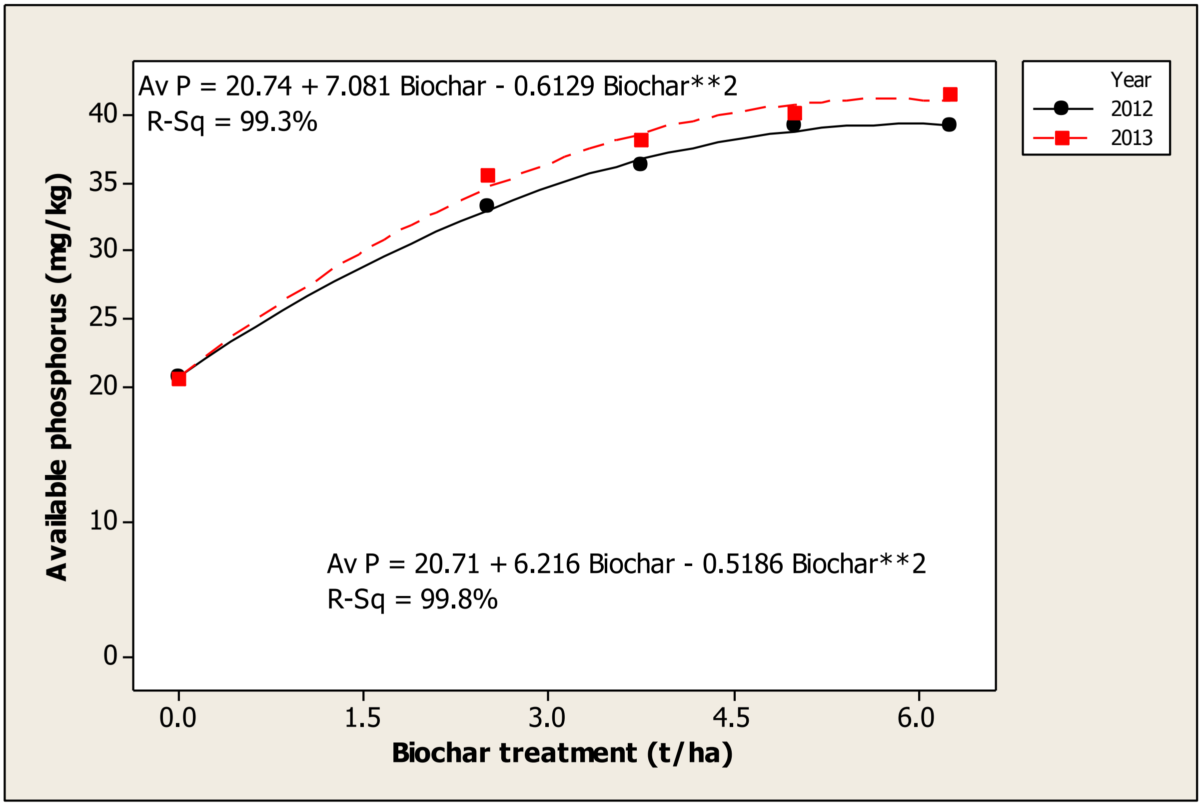

Figure 5. Second-order polynomial regression between biochar treatment and available phosphorus for the two seasons

Table 3. Effect of biochar on soil exchangeable bases and Effective cation exchange capacity (ECEC) (cmolkg^{-1}).

Treatment (t ha^{-1})	Na^+	K^+	Mg^{2+}	Ca^{2+}	ECEC	Na^+	K^+	Mg^{2+}	Ca^{2+}	ECEC
			2012					2013		
0 (C)	0.06	0.08	1.80	3.7	6.6	0.05	0.06	1.60	3.6	6.4
2.5	0.08	0.10	2.00	5.5	8.0	0.07	0.11	2.00	5.2	8.4
3.75	0.09	0.13	2.09	5.5	7.5	0.10	0.15	1.90	5.6	7.9
5.0	0.15	0.13	2.31	5.0	7.9	0.08	0.14	2.40	4.8	8.1
6.25	0.17	0.15	2.34	5.8	8.0	0.10	0.16	2.00	6.4	9.1
FLSD = 0.05	0.10	0.08	1.09	0.13	1.30	0.04	0.10	1.03	1.06	1.20

C = control.

Table 4. Effect of biochar on vine length (cm), fruit length (cm), number of fruits and yield (t ha^{-1}) of cucumber.

Treatment	Vine length	Fruit length	Number of fruits	Yield
2102				
0 (c) t ha^{-1}	43.4	13.6	16	4.81
2.0 “	51.7	15.3	19	5.10
3.75 “	53.4	16.2	20	6.16
5.0 “	57.3	17.1	22	6.20
6.25 “	56.8	16.9	20	6.00
FLSD = 0.05	1.69	1.01	1.28	2.13
2013				
0 (c) t ha^{-1}	42.2	13.4	18	4.70
2.0 “	54.6	15.6	21	6.63
3.75 “	58.6	16.3	23	7.42
5.0 “	61.6	17.2	25	7.50
6.25 “	57.2	14.8	20	4.23
FLSD = 0.05	1.20	0.98	1.33	1.22

C = Control.

was 5.0 > 3.75 > 2.5 > 6.25 t/ha > C. The table also showed higher cucumber yield in biochar amended plots relative to the control. Application of biochar at 5.0 t/ha gave the highest yield in both first and second cropping seasons. The highest yield of 6.20 in 5.0 t/ha in the first cropping season was 37,12, 5 and 47% higher than in C, 2.5, 3.75 and 6.25 t/h rates of application, respectively.

DISCUSSION

Decrease in soil BD following addition of biochar in the present study is in line with the earlier report of Nelissen et al. (2015). The authors observed that addition of biochar into the soil can alter microbial population, shift functional group and reduce BD with a corresponding increase in soil total porosity. Similarly, Brady and Weil (2004) observed that biochar has a lower BD (0.3 Mgm^{-3}) than mineral soil (1.3 Mgm^{-3}) and thus can reduce soil BD to a desirable level for plant growth. Indeed, the addition of biochar reduced bulk density from 1.53 g cm^{-3} in non-treated soil down to 1.44 g cm^{-3} in biochar treated soil (Table 2). Notably, the lowest biochar application rate (2.5 t/ha) soil treatment in the present study had similar bulk density to untreated soils.

A reduction in soil bulk density using similar rates of biochar application has been reported in other studies utilizing hardwood biochar (Ndor et al., 2015), wheat straw (Alburquerque et al., 2014); fronds of date palm (Khalifa and Yousef, 2015), and mixed feedstock obtained from prunnings of fruit trees (Castellini et al., 2015). The result of the current study tends to reaffirm the postulation of Atkinson et al. (2010) that biochar could possibly be part of a long-term adaptation strategy, as it could affect soil physical properties like soil structure, soil bulk density, porosity, particle density and water storage capacity for sustainable agricultural productivity.

Remarkably, the different rates of biochar application in the present study has the potential of enhancing the physical structure of amended soils making them favorable for the growth of cucumbers and increased aeration and water storage, thus improving the soil quality.

In the present study, pH, total N, OC, available P, exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and ECEC were used as chemical or fertility indicators of soil quality for better understanding of the changes that might have occurred as a result of biochar application. The study revealed that the soil was moderately acidic (5.9) before the incorporation of biochar (Table 1). The acidity is typical of the soils of the Southeastern part of Nigeria and is attributed to the parent materials, excessive precipitation which leads to leaching losses of most of the cations in the soil and degradation in soil physicochemical properties (Ano and Ubochi, 2007). The pH values recorded in this study are similar to pH values reported by Okolo (2014) for some other Nigerian soils.

In the present study, addition of different rates of biochar increased soil pH slightly from 5.7 to 6.4 and 5.5 to 6.9 for the two cropping seasons (Figure 2), with all biochar application rates being equally effective and remarkable. This implies that any slight addition of biochar to an acidic soil will give a resultant positive effect in regulating the soil pH. Excessive acidity in arable soils is undesirable because such acidity encourages among other things toxic conditions and also nutrient cation deficiency. It is therefore very necessary and imperative to neutralize excessive soil acidity in order to create optimum and favorable soil environment for plant growth. The increase in soil pH in this study with the application of different rates of biochar corroborates the study of Chan et al. (2008a). Vaccari et al. (2011) in a research with wood biochar pyrolysed at 550°C equally reported an increase in the pH of an acidic (pH = 5.2) silty loam soil at both elevated levels of 30 and 60 t/ha.

The application of different rates of biochar in this study had a significantly ($p < 0.05$) positive effect on SOC in the biochar treated plots compared to control for the two cropping seasons, thus supporting our second hypothesis that applications of different rates of biochar will enhance soil properties and carbon (C) sequestration potential also in a short-term crop. Notably, as a pyrolysed product, biochar is protected from rapid microbial degradation and is able to securely sequester carbon, contributing to mitigation of greenhouse gas emissions (Lehmann et al., 2006). The result of the present study collaborate the recent findings of Angst et al. (2014) who reported that SOC was significantly increased due to the applications of different biochars. Haefele et al. (2011) reported a 66.5% increase in organic carbon contents at elevated level of 41.3 t ha^{-1} (about 4%) using rice husk biochar in a near neutral soil. Similarly, Zhang et al. (2012) recorded 44% increase in soil organic carbon at 20 t ha^{-1} (about 2%) application rate with a wheat straw biochar. Also, in another research, Khan et al. (2013) achieved a 550% increase in total carbon contents in a 5% amendment using sewage sludge biochar in an acidic paddy soil. Markedly, biochar treatment was strongly correlated with total nitrogen (R^2 = 95% and R^2 = 89.7% for 1st and 2nd year, respectively; Figure 3) and SOC (R^2 = 82% and R^2 = 78.4% for 1st and 2nd year, respectively; Figure 4).

The improvement in soil content of total N, available P and basic cations following addition of biochar could be attributed to higher levels of these nutrients in biochar as reported by Preston and Schmidt (2006) and also indicated in the biochar characterization (Table 1). Study by Lehmann et al. (2011) showed that biochar contains high levels of essential nutrients, including P, N, C, CEC and a more neutral pH. The nature and source of biochar, method of pyrolysis and soil type could play an important role in soil properties. For example, mineralization of N could be enhanced by application of biochar produced from slow pyrolysis rather than fast pyrolysis (Bruun et al., 2012), while some studies elsewhere has shown that N in plant-based biochars may be less available than that in biochar from animal manures (Tagoe et al., 2008).

Agegnehu et al. (2015) reported that biochar and composted biochar addition increased soil N by 14 and 29%, respectively. This may be due to the amount of N added and low C: N ratio of the soil, which limits N immobilization. Previous research by Xu et al. (2013) observed that available P increased in biochar amended plots, with the source of P coming from the biochar types used. In the present study, biochar application added very significant amount of available P in amended plots compared to the control (R^2 = 89.7% and R^2 = 87.7% for 1st and 2nd year, respectively; Figure 5), thus inferring that biochar application contributes to the increase in soil available P.

Effective cation capacity is the sum of the cations a soil can adsorb at its natural pH, and is obtained by the summation of total exchangeable bases (TEB) and total exchangeable acidity (TEA). It was observed that the amendment of the soil with different rates of biochar significantly improved the ECEC of the soil, thus indicating that the retention of non-acidic cations by the soils increased (Agegnehu et al., 2015). It can be stated that biochar serving as a soil conditioner tends to increase the availability and retention of plant nutrients in soil, thereby potentially increasing nutrient use efficiency for increased agricultural production in degraded soils.

Glaser et al. (2002) opined that biochar inherently containing ash, adds nutrients such as K, Ca and Mg to the soil solution thereby increasing the pH of the soil and providing readily available nutrients for optimum plant growth. The finding of this study demonstrated positive effects of biochar on SOC content and nutrients levels and is inconformity with the findings of Liu et al. (2012) and Agegnehu et al. (2015). Both studies reported positive effects of biochar on SOC content and nutrients levels under field studies in Dystric Cambisol in Northeast

Germany and Ferrasol in North Australia, respectively.

Improvement in soil properties following application of biochar led to increase in vine length, number of fruits, fruit length and yield of cucumber relative to the control. Notably, the temperature of the study area is within the range that enhances cucumber growth and yield. Earlier studies attributed the effect of biochar on crop yield to associated nutrient retention, increased pH and base saturation, available P and increased plant available water (Agegnehu et al., 2015). The observed significant response of cucumber to different rates of hardwood biochar in the present study collaborates with the previous studies of Carter et al. (2013), and Fagbenro et al. (2015) on the stimulating effect of biochars on tree growth. In this study, 5 t/ha rate of application gave the highest yield, vine length, fruit length and number of leaves for the both cropping seasons.

Yilangai et al. (2014) reported significantly higher yield of tomato in beds treated with charcoal than without charcoal. Similarly, biochar application increased vegetable yields by 4.7 to 25.5% as compared to farmers' practices (Vinh et al., 2014). Most recently in an experiment using green waste biochar at 0, 10, 30, 50 and 100 t/ha rates of application. Upadhyau (2015) observed increased number of leaves, root length, plant height and final biomass using lettuce and potato as test crops.

Despite numerous reports of positive effects of biochar application to soil and improved crop production, as evidenced in the current study, some researchers elsewhere have reported negative effect of biochar on soil and crop production. In a recent investigation, Bargmann et al. (2014) observed that in some cases, biochar application can decrease soil available N and plant tissue N concentration. Also, Jones et al. (2012) did not detect differences in soil bulk density three years after biochar addition in a UK field trial, while more recently; Tammeorg et al. (2014) did not observe an effect of biochar on soil bulk density and porosity in the field.

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 of 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.

Conclusion

The results of our study showed that improvements in soil properties due to biochar application led to increased vine length, number of fruits, fruit length and yield of Cucumber. On the average, application of biochar at 6.25 t ha-$^{-1}$ resulted to the highest improvement in soil properties in both seasons while the highest increase in cucumber yield and other agronomic properties were observed in 5 t ha^{-1} rate of application. The results indicated that different rates of biochar application added as soil amendment has the potential of improving soil quality and boosting productivity of cucumber in a degraded Ultisol. More long term and periodic field studies are urgently needed in different soil types and climatic regions to fully understand the benefits of different biochar sources/rates and equally to confirm/negate some of the observations made in view of fostering robust interdisciplinary scientific research.

Conflict of Interests

The authors have not declared any conflict of interests.

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