EFFECT OF BIOCHAR ON SOIL NUTRIENT STATUS AND THE PERFORMANCE OF CUCUMBER ON AN ULTISOL IN UMUDIKE, SOUTH EASTERN NIGERIA.

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ABSTRACT
A field experiment and laboratory analysis were carried to investigate the effects of biochar on soil nutrient status and the performance of cucumber (Market More) on Ultisol in Umudike, South Eastern Nigeria. The treatments were (0,1,3 and 5) tonne per hectare biochar respectively and (1,3,5) tonnes biochar + 400kg NPK (15:15:15) per hectare respectively and 400kg NPK (15:15:15) per hectare. The treatments were replicated 3 times. The field experiment was laid out in a RCBD. The soil was strongly acidic, with a pH (H_2O) of 4.50 and EA of 1.44 cmolkg^{-1}. The soil was also low in organic matter content (1.63%) and exchangeable bases ((Ca, Mg, K and Na) had (2.80, 1.60, 0.21, and 0.18) cmolkg^{-1} respectively.) Soil samples were collected at 4, 8 and 12 weeks after planting (WAP) to study the effect of biochar on the soil nutrient status. The performance of the cucumber in the field showed a significant ($P<0.05$) increase in the number of leaves and vine length of cucumber by 3 tonnes biochar + 400 kg NPK (15:15:15) per hectare over other treatments. The soil nutrient analysis showed that biochar significantly increased the organic matter content of the soil during the experiment with the highest increase recorded at 12 WAP. In Conclusion, the experiment indicated that the application of biochar as soil amendment can viably ameliorate soil acidity, enhance nutrient status of ultisol and invariably improve cucumber growth in the soils of the study area.

***Keywords**: Biochar, Soil Nutrient, Cucumber, Ultisol, Umudike.*

INTRODUCTION
Soils found in southeastern Nigeria which is characterized by high acidity and low rate of exchangeable cations cannot support optimal crop production without the use of soil amendment (Onwuka *et al.*, 2006). The application of biochar, has been proven to change soil pH to a more neutral pH, especially in acidic soils (Fowles, 2007). Biochar is known to have the capability of reducing soil compaction, improving soil physical condition, enhancing plant nutrient uptake from the soil and decreases emission of nitrous oxide (Lehmann *et al*., 2005; Lehmann 2007; Kannan *et al*., 2012). Biochar has the potential to increase the availability of plant nutrients (Lehmann *et al.*, 2008); through increasing cation exchange capacity (CEC), improving soil pH, or immediate nutrient contributions from the biochar itself. According to (Mbagwu and Piccolo 1997) the potential mechanism for improved nutrient retention and supply due to biochar modification is the increase of cation exchange capacity up to 50% as compared to unamended soils. Biochar has a greater capacity to absorb and retain cations than other forms of soil organic amendment owing to its greater surface area, and the negative surface charge that is found on biochar (Liang *et al*., 2006; Abukari, 2014).
Cucumber (*Cucumis sativus* L.) is an important vegetable, thought to be one of the oldest vegetables with historical records dating as far back as 5000 years (Wehner and Guner, 2004). The crop is cultivated mainly for its fruits and eaten fresh (salad). The

fruit is rich in nutrients and vitamins such vitamin E, K, C, A among others; minerals such as magnesium, potassium, zinc, calcium and phosphorus as well as phyto-nutrients like Carotene-B, Xanthein-B and Lutein (Vimale *et al*., 1999; Nwofia *et al*., 2015). The crop requires fertile soils as infertile soils affects the quality of the fruit resulting in bitter and misshapen fruits (Eifediyi and Remison, 2010). As a short gestation crop, cucumber requires instant release of nutrient in the field which inorganic fertilizer can supply better than organic fertilizer (Marjan, 2005). However, under intensive agriculture, the use of inorganic fertilizer has not been helpful because of the high cost, associated reduction in the crop yields, nutrient imbalance, soil degradation and acidity (Kang and Juo, 1980; Obi and Ebo, 1995; Eifediyi and Remison, 2010).
Therefore, the aim of this study was to evaluate the effect of biochar on soil nutrient status and the performance of cucumber planted on an Utisol in Umudike.

MATERIALS AND METHODS

Description of Experimental Site÷
A field experiment was carried out at the Eastern farm of Michael Okpara University of Agriculture, Umudike, Abia State. Nigeria located in the tropical rain forest. This area has a mean annual rain fall of 2117 mm distributed over 9 to 10 months in a bimodal rainfall pattern. Monthly average air temperature ranges from 20 – 24 ^{o}C and 28 ^{o}C.

Soil sampling÷
Initial soil samples were collected randomly from the experimental site at a depth of 0-20cm with a soil auger, bulked together and the composite sample was sent to the laboratory where it was air dried, crushed and sieved through a 2mm sieve for routine soil analyses using standard procedures.÷
Particle size distribution was determined by Bouyoucos hydrometer method as modified by Gee and Bauder (1986).
Soil pH was determined using a suspension of soil and distilled water in the ratio of 1:2.5 soils: water, and the pH value read with the aid of a glass electrode pH meter (Thomas, 1996).
Available Phosphorus was determined using Bray 11 method (Olsen and Sommers, 1982).
Total Nitrogen was determined following the Micro Kjeldahl digestion procedure (Bremner and Mulvaney, 1982).
Organic Carbon was determined based on Walkey-Black chromic acid wet oxidation method.
Soil exchangeable Calcium (Ca), Magnesium (Mg), Sodium (Na), and Potassium (K) were extracted with neutral ammonium acetate. Calcium and magnesium in the extracted leachate was determined by Ethylene Diamine Tetra-acetic Acid (EDTA) titration method as described by Lanyon and Heald (1984) while Sodium and Potassium were determined by flame photometric method (Kundsen *et al*., 1982).
Soil exchangeable acidity (Al^{3+} and H^{+}) was determined using the 1N KCl extractant method of Mclean (1982) as described by Udo *et al*. (2009).
These routine analyses were carried out before biochar application, at 4 weeks after biochar application and subsequently at 8 and 12 weeks after biochar application to assess the effect of the biochar on the soil properties by comparing the variations on the values obtained from each treatment.

Field Experiment
The farm site was slashed, ploughed and harrowed and the surface brought into fine tilth and marked out. The experiment was laid out in Randomized Complete Block Design (RCBD), replicated three times with 8 different treatment rates of biochar. The plot size was 3 m x 4 m (12 m^2). A planting distances of 75 cm x 75 cm, and inter row spacing of 1 m between experimental units and 2 m distance between the experimental plots was used. The variety of cucumber that was sown was “Market More” and two seeds of cucumber were sown per hole. Weeds were controlled manually by using weeding hoe. The crops were sprayed with “karate” insecticide, at 6 WAP to control insects and the fungicide benomyl (benlate) was used to protect the crop against fungal attack.

Treatments
The treatment used was biochar and NPK (15:15:15) fertilizer, applied at the following rates:

Treatment 1	T_1 = zero tonne per hectare of biochar (control)
Treatment 2	T_2 = 1 tonne per hectare of biochar
Treatment 3	T_3 =1 tonne per hectare of biochar + 400 kg per hectare NPK (15:15:15)
Treatment 4	T_4 = 3 tonnes per hectare of biochar
Treatment 5	T_5 = 3 tonnes per hectare of biochar + 400 kg per hectare NPK (15:15:15)
Treatment 6	T_6 = 5 tonnes per hectare of biochar
Treatment 7	T_7 = 5 tonnes per hectare of biochar + 400 kg per hectare NPK (15:15:15)
Treatment 8	T_8= 400 kg per hectare NPK (15:15:15)

Biochar Production
Biochar was produced locally using the following organic residues (150 kg of saw dust, 150 kg of cocoa pod, 150 kg of palm bunch, 150 kg of rice husk and 250 kg of poultry droppings). Animal dung (Poultry droppings) was sourced from Michael Okpara University of Agriculture Animal farm. Saw dust from Timber Market Ahieke and rice husk from Bende rice mill in Uzoakoli LGA, Abia State. Cocoa pod and palm bunch were sourced locally from farmers in Umudike.

The biochar so produced was sent for analysis to determine both the physical and chemical properties of the biochar product.

Biochar Application
The biochar was surface applied before being incorporated into the soil using hoe. And this was done one week before planting.

Growth Data Collection
The following growth data were collected at 3 and 6 WAP: Vine length (using flexible tape rule) and number of leaves (by visual count of the green leaves).

Statistical Analysis
Data collected were subjected to Analysis of Variance (ANOVA) using GenStat software. Mean separation was done according to Obi (2002) using the Fischer’s Least significant difference where significance existed.

RESULTS AND DISCUSSION

Initial Soil Analysis
The chemical and physical properties of the soil used for this study are presented in Table 1. The physical analysis of the soil showed that it contained 79.60% sand,

8.00% silt and 12.40% clay making the textural class sandy loam. The soil pH was strongly acidic (4.50), based on the pH interpretation rating given by Chude *et al*. (2005) and the value corroborated with the findings of Akinmutimi and Ihejirika (2016) who reported that soils around the south east especially in Umudike are acidic. Most of the soils of South eastern Nigeria are acidic due to the nature of the parent material, weathering and heavy leaching of basic cations such as calcium and magnesium leaving behind aluminum and iron oxides and hydroxides (Akinmutimi and Osodeke, 2013; Brady and Weils, 2008). The organic carbon content was 0.94% while the organic matter content was 1.63% thus rated low (< 2.0%) based on organic matter ratings of south eastern Nigeria soils by Enwezor *et al*. (1990). The low organic matter content of the soil can be attributed to the effect of temperature, soil management and the nature of the soil texture (sandy loam) which is well aerated, and the presence of oxygen results in a more rapid decay of organic matter (Doran and Smith 1987). Nitrogen content was low (0.056%) which is a common occurrence in soils of southeastern Nigeria as a result of losses arising from leaching of nitrates as well as the rapid mineralization of organic matter under the isohyperthermic soil temperature regime (Ahukaemere *et al*., 2014; Eshett *et al*., 1990; Eshett, 1987). The Phosphorus content was low (12.50 $mgkg^{-1}$) which is below the critical level of 15 $mgkg^{-1}$for southeastern Nigeria (Enwezor, 1989). This is a well-known occurrence in the soils of south eastern Nigeria and is attributed to the high rate of phosphate fixation capacity of the soil arising from the highly acidic nature of the soil (Ahukaemere *et al*., 2014; Idigbor *et al*., 2008). In acidic soils, the oxides of aluminium and iron fix phosphorus to form complexes that are insoluble and thereby rendering phosphorus unavailable in the soil (Lee *et al*., 2010; Onwuka *et al*., 2009). Exchangeable Aciditity was 1.44 $cmolkg^{-1}$ and the soil had Exchangeable bases (Ca, Mg, K and Na) of (2.80, 1.60, 0.21, and 0.18)$cmolkg^{-1}$ respectively. The low value of Exchangeable potassium (0.21$cmolkg^{-1}$) can be attributed to low potassium reserve in acid soils. This may be caused by the highly mobile nature of exchangeable potassium relative to calcium and magnesium and its consequent massive loss through leaching (Ahukaemere *et al*., 2014). The values obtained for other exchangeable bases were low and agreed with the findings of Nwite *et al*. (2009); Ovie *et al*. (2013) and Akinmutimi and Ihejirika (2016) who reported that Ultisols of southeastern Nigeria were low in exchangeable bases. The low values of exchangeable bases can be attributed to high rainfall and consequent leaching of basic cations out of the root zone of the soil.

Table1: Physical and chemical properties of the soil used for the field experiment

Parameter	Values
Soil pH (1:2.5) H_20	4.50
Total Nitrogen (%)	0.06
Organic Carbon (%)	0.94
Organic Matter (%)	1.63
Available Phosphorus ($mgkg^{-1}$)	12.50
Exchangeable Calcium ($cmolkg^{-1}$)	2.80
Exchangeable Potassium ($cmolkg^{-1}$)	0.21
Exchangeable Magnesium ($cmolkg^{-1}$)	1.60
Exchangeable Sodium ($cmolkg^{-1}$)	0.18
Exchangeable Acidity ($cmolkg^{-1}$)	1.44
Sand (gkg^{-1})	796.00
Silt (gkg^{-1})	80.00
Clay (gkg^{-1})	124.00
Soil Texture	SL

Biochar Analysis

The following feedstock (Saw dust, Cocoa pod, palm bunch, rice husk and poultry droppings) were subjected to slow pyrolysis to produce biochar which was mixed together and analyzed. The results obtained are shown in Table 2.

The biochar had a pH of 9.70; similar pH value was obtained from a study where cocoa shell and rice husk were subjected to slow pyrolysis (Smebye, 2014). Organic carbon content was 1.54%. Nitrogen content was 0.91% and organic matter content was1.72%. Phosphorus was 0.58%. Potassium content was 1.96%, calcium content was 9.24%, sodium content was 0.19% and magnesium content was 4.13%. The exchangeable bases were relatively higher in the biochar when compared to that of the soil used for this study. This indicates the potential of the biochar to enhance the chemical properties of the soil under study

Table2

Parameters	Values
pH (H_20)	9.70
Organic carbon (%)	1.54
Organic Matter (%)	1.72
Nitrogen (%)	0.91
Phosphorus (%)	0.58
Potassium (%)	1.96
Calcium (%)	9.24
Magnesium (%)	4.13
Sodium (%)	0.75

Effect of the treatments on Soil pH during the field experiment

The treatments had significant effect on the soil pH at 4 weeks after application (4WAA). Similarly, Yeboah *et al*. (2009) and Oguntunde *et al*. (2004) reported an improvement in soil pH after biochar application in field trials.

At 8WAA, the plots treated with higher rates of the amendment T_6 (5 t ha^{-1} B) and T_7 (5 t ha^{-1} B+ 400 Kg ha^{-1} NPK) gave higher pH values than those treated with lower rates of biochar. The lowest pH value was obtained from the control.

At 12 WAA, all treatment had pH values that were significantly ($P<0.05$) higher than the control. Table3

The increase in the pH may also be attributed to the alkaline nature of the biochar (Sukartono *et al*., 2011) and this is in line with the findings of Zhang *et al*. (2010) and several other researchers (Chan *et al*., 2007; Novak *et al*., 2009; Laird *et al*., 2010; Van Zwieten *et al*., 2010; Peng *et al*., 2011) who claimed that biochar improved soil pH thus reducing lime requirement.

The ash content of biochar is principally accountable for the modification of the soils pH. The ash content in biochar is usually alkaline and could potentially increase soil pH when added to an acidic soil (Chintala *et al*., 2014).

Table 3

Parameter	Values
Soil pH (1:2.5) H_20	4.38
Total Nitrogen (%)	0.04
Organic Carbon (%)	0.34
Organic Matter (%)	0.59
Available Phosphorus (mgkg^{-1})	16.40
Exchangeable Calcium (cmolkg^{-1})	3.20
Exchangeable Potassium (cmolkg^{-1})	0.17
Exchangeable Magnesium (cmolkg^{-1})	2.00
Exchangeable Sodium (cmolkg^{-1})	0.19
Exchangeable Acidity (cmolkg^{-1})	1.84
Sand (gkg^{-1})	772.00
Silt (gkg^{-1})	150.00
Clay (gkg^{-1})	78.00
Soil Texture	SL

Effect of the treatments on the other chemical properties of the soil

There were increase in soil organic carbon content and organic matter content from the following treatments; T_2 (1 t ha^{-1}B), T_4 (3 t ha^{-1}B) and T_6 (5 t ha^{-1} B). The application of biochar also increased elemental plant nutrients N, P, K, Ca, Mg and Na as the rate of application increased. These increases agree with results obtained by Glaser (1999). The increase in elemental plant nutrient can be attributed to the nutrient content of the biochar. The removal of aluminum antagonist from nutrient uptake by the ash property of the biochar could also be responsible for the increase in potassium, calcium and magnesium Onwuka *et al*. (2006).

The application of the treatments significantly increased the organic matter content of the soil at 4WAA, 8WAA and 12WAA compared to the control. At 4 WAA mean value for organic matter was 1.48 and increased to 1.68 at (8WAA) and then 1.77 at (12WAA). The plots treated with inorganic fertilizer (T_8= 400 Kg ha^{-1} NPK) had the highest value of organic matter content 1.13, 2.65 and 2.55% at 4 WAA, 8 WAA and 12 WAA respectively. The lowest organic matter content of 0.77% was observed at treatment T_3 (1 t ha^{-1}B + 400 Kg ha^{-1} NPK) at 4WAA. At 8WAA control (T_1 = 0 t ha^{-1}) had the lowest value 0.83% of organic matter content. At 12WAA, there was significant ($P<0.05$) increase across all treatment rates compared to the control which had the lowest organic matter content. However, the highest value of organic matter content (2.55%) was observed in treatment T_8 (400 Kg ha^{-1} NPK). The high value of organic matter observed at the plot treated with 400 Kg ha^{-1} NPK(15:15:15) fertilizer may be due to fast rate of decomposition of the inorganic fertilizer as compared to the recalcitrant nature of biochar.

According to Cheng *et al*. (2006) and Bruun and Luxoi (2008) biotic processes generally have slow impact on char decomposition in the short term.

Effect of the treatments on growth of Cucumber

The treatments had highy significant ($P<0.01$) effect on the vegetative growth parameters of cucumber. At 3WAP, the highest number of leaves (11.40) and vine length (27.50 cm) was recorded from treatment T_5 (3 t ha^{-1}B + 400 Kg ha^{-1} NPK) and the control (T_1 = 0 t ha $^{-1}$) had the lowest number of leaves (4.60) and vine length (17.00 cm). Also at 6WAP treatment T_5 (3 t ha^{-1}B + 400 Kg ha^{-1} NPK) produced the highest number of leaves (35.27) and vine length (127.60 cm). Increased rate of biochar and its combination with fertilizer resulted in a decline in number of leaves and vine length. Treatment T_6 (5 t ha^{-1} B) produced (25.00) leaves and (118.00 cm) vine length while treatment T_7 (5 t ha^{-1} B+ 400 Kg ha^{-1} NPK) gave (25.63) leaves and (119.0 cm) vine length at 6 WAP. The decline in the number of leaves and vine length at higher rate of biochar can be attributed to over-optimal supply of potassium from the biochar. Excess potassium causes nitrogen deficiency in cucumber and may also interfere with the uptake of other Cations such as Magnesium and Calcium resulting in impaired vegetative growth of the crop. Results obtained from treatment T_8 (400 Kg ha^{-1} NPK) at 6 WAP for number of leaves (26.83) was similar to that obtained by Eifediyi and Remison (2010). The rigorous growth in cucumber as occasioned by the application biochar and NPK fertilizer which is evident in the Vine length and Number of leaves produced per plant is in agreement with the reports of Fuchs *et al*. (1970) and Eifediyi and Remision (2010) that attributed enhance crop establishment to nutrients obtained from the amendments. Balance nutrition plays an important role in the optimal performance of a delicate crop like cucumber. Glacier *et al*. (2002) indicated that the use of biochar along with synthetic fertilizer increases bioavailability and uptake of Phosphorus and reduces nutrient leaching losses (Lehmann, 2007.

CONCLUSION

The results obtained from this study proved that biochar is an effective acid neutralizing agent (liming material) in ameliorating the acidity problem of this region; the equivalent of 1 tonne of biochar per hectare was found to be sufficient in increasing pH and reducing exchangeable acidity, thereby neutralizing acidity in the ultisol of Umudike and could also buffer the pH capacity of the soil significantly.

Based on the field trial, 3tonnes of biochar combined with 400 Kg ha^{-1} NPK (15:15:15) was found to be effective in neutralizing soil acidity, improving soil nutrient status and enhancing the release of nutrients necessary for the growth of cucumber. Therefore, based on the soil pH response of this study. The use of 1 tonne per hectare biochar is recommended as a liming material to modify soil acidity and also its combination with inorganic fertilizer (3 tonnes of biochar combined with 400 Kg ha^{-1} NPK -15:15:15) to enhance the release of nutrients for optimal growth performance.

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