Use of Biochar to Improve Selected Soil Chemical Properties, Carbon Storage and Maize Yield in an Ultisol in Abakaliki Ebonyi State, Nigeria

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Abstract— *An experiment was carried out at Teaching and Research Farm of Faculty of Agriculture and Natural Resources Management, Ebonyi State University, Abakaliki to evaluate the effect of biochar on soil chemical properties, carbon storage and maize performance in an Ultisoil in Abakaliki, Southeastern Nigeria. The experiment was laid out in randomized complete block design (RCBD) with four treatments replicated five times. Data collected were analysed using the General Linear Model of SAS software in RCBD and significant difference dictated using F-LSD. Soil samples were collected and analysed for organic carbon, total nitrogen, pH, available P, exchangeable bases and exchangeable acidity while crop performance measured were maize height and maize grain yield. Results of the study showed that biochar amended plots had significant ($P < 0.05$) higher organic carbon, total nitrogen, pH, available P, exchangeable bases, exchangeable acidity, carbon storage, maize height and maize grain yield than control. Also, there was an increase in the magnitude of the parameters with an increase in the rate of biochar applied. This study recommends that biochar should be used as soil amendments to increase soil productivity and carbon storage in the soil to reduce the amount of CO_2 emitted to the atmosphere.*

Keywords— Biochar, CO_2 emissions, Maize yield, Soil productivity

I. INTRODUCTION

Biochar, short form for bio-charcoal is plant derived carbon obtained through pyrolysis of plant various origins. It is mostly composed of carbon and comes in the form of small black and highly porous fragments. It may also contain organic molecules. Biochar has been the focus of increasing interest as it claimed to be a way to almost permanently lock atmospheric carbon of unused plant residue (that would otherwise limit CO_2 during natural decomposition), which is transported through pyrolysis into stable black carbon and various gas products. This carbon is then ploughed into the soil, where it is permanently stored, while almost enhancing the soil productivity. The biochar physicochemical properties can cause changes in the soil nutrient and C availability, and provide physical protection to microorganisms against predators and desiccation; this may alter the microbial diversity and taxonomy of the soil (Lehman *et al.,* 2011). Biochar addition to the soil have been found to stimulate mycorrhizal infection (Satio, 1999; Ishii and Kadoya, 1994) and influence phosphorus solubility in forest soil (Gundaie and Deluca, 2007) which may be responsible for observe increase in phosphorous uptake. The mediation of nutrient turnover by biochar has significant implication for organic agricultural system where biochar may increase the stabilization or organic nutrient source (Glaser *et al.,* 2001) and reduce nutrient leaching losses (Lehmann *et al*., 2003). Addition of biochar to soil provides a modest contribution of nutrient depending, in part upon the nature of the feed stock and upon the temperature under which the material is found (Bridle and Pritchard, 2004; Gundale and Deluca, 2006). Biochar boost the cation exchange capacity (CEC) of soils, reduces aluminum toxicity in some soils, reduce nutrient leaching especially nitrate and also restructure soil to improve soil physical properties. However, biochar is more important as soil conditioner and driver of nutrient (Berglund *et al.,* 2004).The total carbon content of biochar varies considerably depending on feedstock and may range from 400gkg-^{1} up to 900gkg-^{1} (Antal and Gronli 2003; Chan and Xu, 2009; Gaskin, *et al.*, 2010). The highest carbon content is obtained from hard wood feed stocks pyrolyzed at high temperatures. Biochar is first and foremost characterized by its high organic carbon content which mainly comprises conjugated aromatic compounds for six carbon atoms linked together in rings. Beside the large carbon component, the elemental composition of biochar consist of hydrogen and oxygen, as well as different minerals for example Nitrogen, Phosphorus, suphur depending on the feedstock (Lehmann, *et al*, 2009). Researches on biochar as soil amendment are very few in the study area. Therefore, the main objective of this study is to determine the effect of biochar on soil chemical properties, carbon storage and maize performance in an Ultisol in Abakaliki, Southeastern Nigeria.

II. MATERIAL AND METHOD

2.1 Study Site

The experiment was carried out at the Teaching and Research Farm of the Faculty of Agriculture and Natural Resources Management, Ebonyi State University Abakaliki, Southeastern Nigeria. The area lies on longitude $5^0$35 N – $6^0$45'N and latitude $7^0$45'E – $8^0$30' E in the derived savannah zone of southeastern Nigeria and is characterized by high rainfall and high temperature which ranged between 1800mm – 2000mm and 21^0C – 29^0C, respectively. The relative humidity is between 60 – 80%. The soil is hydromorphic and belongs to the order Ultisol, within the Ezzamgbo soil association, derived from shale and classified as typic Haplustult (Federal Department of Agriculture and Land Resources, 1985). The soils have been noted to be acidic, low in organic matter status, cation exchange capacity and other essential nutrients, (Enwezor *et al*., 1988, Asadu and Akamigbo, 1990, Nnabude and Mbagwu 1999 and Ogbodo and Nnabude, 2004).

2.2 Materials

The major materials used for the experiment are biochar and maize (Oba super 11), which were purchased at Eke Aba Market, Abakaliki and Ebonyi State Agricultural Developmental Programme (EBADP), respectively.

2.3 Land Preparation

The experimental site measured 16 m X 18 m (0.0288 ha) was on a flat terrain which had been on fallow for a year and comprised of vegetations such as *Imperata cylindrical, Panicum maximum, Manihot spp and Odoratum spp.* The vegetation was cleared manually using matchet and the debris was removed before making the bed using hoes.

2.4 Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with four treatments and five replications. A total of 20 plots each measuring 3 m X 3 m (9 m^2) were used for the experiment. Plots were separated by 0.5 m and each replicate was 1 m apart. Treatments were biochar at 0, 5, 10 and 15tha^{-1}. Treatments were incorporated to the plots after making the bed using hoes. Two maize seeds (var. Oba super 11) were planted per hole 2 weeks after treatment application. Planting was done at a spacing of 25 cm within rows and 75 cm between rows while the planting depth was 3 cm. The seedlings were thinned down to a plant per stand two weeks after germination (WAG). Lost stands were replaced. Weeding was done manually at three weeks interval till harvest. There was non-application of fertilizers, herbicides and pesticides to the plots and the crop was raised under rainfed system.

2.5 Soil Sampling

Initial soil samples were collected randomly from twenty observational points in the site at the depth of 0 – 20 cm before the experiment. The samples were thoroughly mixed to form a composite soil sample and used for pre-planting soil analysis. Also, auger soil samples were collected from three observational points at depth of 0 – 20 cm in each plot immediately after crop harvest. The auger soil samples were air-dried, sieved with a 2 mm sieve and stored in labelled polythene bags and used immediately for soil chemical analysis. Similarly, selected chemical components of biochar were analysed.

2.6 Laboratory Analysis

- **Soil pH:** The pH of the soil was determined in distilled water using a soil/liquid ratio of 1:2.5. After stirring for 30 minutes the pH value was read using a glass electrode pH meter (McLean, 1982).
- **Total Nitrogen**: This was determined using modified kjeldahl digestion procedure (Bremmer and Mulvaney, 1982).
- **Organic Carbon:** Organic carbon was determined by the method of Nelson and Sommers (1982).
- **Available phosphorus:** Available P was determined using Bray II method as outlined by Olsen and Sommers (1982).

- **Exchangeable bases:** The complexiometric titration method, described by Chapman (1982), was used for the determination of Ca and Mg while Na and K were determined from 1N ammonium acetate (NH_4OAC) using the flame photometer.

- **Carbon Storage:** This was calculated as follows:

  Carbon storage = % Organic carbon /100 X Bulk density X Soil collection area X Soil collection depth (Rowell, 1994).

- **Maize growth:** Ten maize plants per plot were sampled for plant height at 90 DAPS. Plant height was measured from the ground surface to the tip of the plant using a metre rule.

- **Maize grain yield**: At maturity 10 maize plants per plot were selected and tagged. The grain yields from the tagged plants were harvested, dried to 11 % moisture content. Grains per plot were weighed and then converted to its hectare equivalent.

2.7 Data Analysis

Statistical analysis of the data was carried out using the General Linear Model of SAS software for Randomized Complete Block while differences between treatment means were dictated using FLSD (Statistical Analysis System Institute, Inc., 1999).

III. RESULTS

3.1 Pre-planting Properties of the Soil

The result of pre-planting properties of the soil is as shown in Table 1. The texture of the studied soil was sandy loam, consisting 720 gkg^{-1}, 182 gkg^{-1} and 98 $gkg^{-1}$of sand, clay and silt, respectively. Soil pH was 6.10 whereas soil organic carbon (OC) and total nitrogen (total N) were 12.1gkg^{-1} and 1.62 gkg^{-1}, respectively. The soil C/N ratio of 8:1 was recorded. The exchangeable bases were 2.40 Cmol(+) of magnesium (Mg^{2+}), 3.60 Cmol(+)$kg^{-1}$of calcium (Ca^{2+}), 0.117 Cmol(+)$kg^{-1}$of potassium (K^+) and 0.189 Cmol(+)kg^{-1} of sodium (Na^+) whereas exchangeable acidity (EA) was 0.24 Cmol(+)kg^{-1}.

TABLE 1
PRE-PLANTING PROPERTIES OF THE SOIL

Test parameter	Value
Sand	720 gkg^{-1}
Clay	182 gkg^{-1}
Silt	98 gkg^{-1}
Textural Class	Sandy loam
pH(H_2O)	6.10
Organic carbon	12.1 gkg^{-1}
Total nitrogen	1.62 gkg^{-1}
C:N	8:1
Available P	33.60 gkg^{-1}
Mg^{2+}	2.40 Cmol(+) kg^{-1}
Ca^{2+}	3.60 Cmol(+) kg^{-1}
K^+	0.117 Cmol(+) kg^{-1}
Na^+	0.189 Cmol(+) kg^{-1}
Exchangeable acidity	0.24 Cmol(+) kg^{-1}

3.2 Chemical Properties of Biochar

Table 2 shows chemical properties of biochar. The pH, OC, total N, C/N ratio and available P of the biochar were 9.64, 826 gkg^{-1}, 8.4 gkg^{-1}, 98:1 and 43.60 $mgkg^{-1}$, respectively. The exchangeable bases were 2.40 Cmol(+)kg^{-1} , 3.40 Cmol(+)kg^{-1}, 7.7 Cmol(+)kg^{-1} and 0.4 Cmol(+)kg^{-1} for Mg^{2+}, Ca^{2+}, K^+ and Na^+, respectively. The EA of the biochar was 0.38 Cmol(+)kg^{-1}.

TABLE 2
COMPOSITION OF BIOCHAR

Test parameter	Value
pH(H_2O)	9.64
Organic carbon	826 gkg^{-1}
Total nitrogen	8.4 gkg^{-1}
C:N	98:1
Available P	43.60 gkg^{-1}
Mg^{2+}	2.40 Cmol(+) kg^{-1}
Ca^{2+}	3.40 Cmol(+) kg^{-1}
K^+	7.7 Cmol(+) kg^{-1}
Na^+	0.4 Cmol(+) kg^{-1}
Exchangeable acidity	0.38 Cmol(+) kg^{-1}

3.3 Effect of Biochar on Soil pH, Total N, OC and Available P

The effect of biochar on soil pH, total N, OC and available P is as presented on Table 3. The application of biochar significantly ($P < 0.05$) increased soil pH, total N, OC and available P relative to the control. The higher the quantity of biochar applied, the higher the magnitudes of these parameters studied. The lowest pH value of 5.6 was recorded on T_1. This value was lower than pH of T_2, T_3 and T_4 by 5, 7 and 9%, respectively. The order of increase in total N was $T_4 > T_3 > T_2 > T_1$. The lowest OC value of 1.78 gkg^{-1} was observed in control while OC values in biochar treated plots ranged between 1.78 – 2.10 gkg^{-1}. Similarly, the order of increase in the value of available P was $T_4 > T_3 > T_2 > T_1$.

TABLE 3
EFFECT OF BIOCHAR ON SOIL pH, TOTAL N, OC AND AVAILABLE P

Treatment	pH	N (gkg^{-1})	OC (gkg^{-1})	Available P ($mgkg^{-1}$)
T_1	5.60	0.098	1.78	23.10
T_2	5.90	0.112	1.82	25.78
T_3	6.0	0.198	1.86	44.20
T_4	6.1	0.280	2.10	63.10
FLSD (p<0.05)	0.30	0.13	1.0	0.70

Where T_1 (Control) = 0 tha^{-1}, T_2 = 5 tha^{-1}, T_3= 10 tha^{-1} and T_4 = 15 tha^{-1}

3.4 Effect of Biochar on Exchangeable Bases and Exchangeable acidity

Table 4 shows the effect of biochar application on exchangeable bases and exchangeable acidity.

TABLE 4
EFFECT OF BIOCHAR ON EXCHANGEABLE BASES AND EXCHANGEABLE ACIDITY (Cmol(+)kg^{-1})

Treatment	Ca	Mg	K	Na	EA
T_1	4.80	2.40	0.072	0.240	0.08
T_2	5.60	2.80	0.082	0.242	0.16
T_3	8.00	3.20	0.097	0.290	0.16
T_4	8.10	4.00	0.100	0.295	0.16
FLSD ($p \leq 0.05$)	2.2	1.6	0.6	0.2	0.29

The effect of biochar treatment on exchangeable bases and acidity showed significant ($P < 0.05$) increase in the various treated plots compared to control. Also, exchangeable bases increased with an increase in the rate of biochar applied. The lowest Ca value of 4.80 Cmol(+)kg^{-1} observed in the control was lower than Ca in T_2, T_3 and T_4 by 14, 43 and 45%, respectively. The order of increase in Mg was $T_4 > T_3 > T_2 > T_1$. Similarly, the lowest K value of 0.072 Cmol(+)kg^{-1} was observed in the control while K values in biochar treated plots ranged between 0.082 – 0.100 Cmol(+)kg^{-1}. The lowest Na value of 0.240 Cmol(+)kg^{-1} was observed in the control. This lowest Na value recorded in control was lower than Na values in T_2, T_3 and T_4 by 1, 21and 23%, respectively. Control recorded the lowest EA value of 0.08 Cmol(+)kg^{-1} while T_2, T_3 and T_4 each recorded EA values of 0.16 Cmol(+)kg^{-1}

3.5 Effect of Biochar on Carbon Storage

Changes in carbon storage following addition of biochar are shown in Table 5. The Table shows significant ($P < 0.05$) increase in carbon storage of the biochar treated plots relative to control. Also, the higher the quantity of biochar applied, the higher the carbon storage observed. Control recorded the lowest carbon storage of 0.94kgha^{-1}. This observed carbon storage in control was lower than carbon storage in T_2, T_3 and T_4 by 4, 12 and 21%, respectively.

TABLE 5
EFFECT OF BIOCHAR ON CARBON STORAGE (kgha^{-1})

Treatment	Carbon Storage
T_1	0.94
T_2	0.98
T_3	1.05
T_4	1.14
FLSD	0.5

Where T_1 (Control) = 0 tha^{-1}, T_2 = 5 tha^{-1}, T_3= 10 tha^{-1} and T_4 = 15 tha^{-1}

3.6 Effect of Biochar on Maize Growth and Grain Yield

Results of the effect of biochar on maize height and maize grain yield are shown in Table 6. There was a significant ($P < 0.05$) increase in maize height and maize grain yield in biochar treated plots compared to the control. The Table also showed that increasing the rates of biochar result to an increase in maize height and grain yield. The lowest maize height value of 109.50 cm was recorded in control. This observed value in control was lower than maize height in T_2, T_3 and T_4 by 27, 42 and 81%, respectively. Similarly, the lowest maize grain yield of 511.11 kgha^{-1} was observed in the control while that of biochar treated plots ranged between 600.0 – 666.67 kgha^{-1}.

TABLE 6
EFFECT OF BIOCHAR ON MAIZE HEIGHT AND GRAIN YIELD

Treatments	Maize height (cm)	Maize Grain yield (kgha^{-1})
T1	109.50	511.11
T2	138.92	533.33
T3	155.39	600.00
T4	191.06	666.67
FLSD (P<0.05)	29.05	33.90

Where T_1 (Control) = 0 tha^{-1}, T_2 = 5 tha^{-1}, T_3= 10 tha^{-1} and T_4 = 15 tha^{-1}

IV. DISCUSSION

4.1 Pre-planting Properties of the Soil

The result of pre-planting soil properties (Table 1) showed that the soil studied was a sandy laom. Sandy laom is highly permeable and allows large quantities of leachates to pass through it (Anikwe and Nwobodo, 2002). As a result of high permeability, this soil contains poor plant nutrients and therefore, need the application of amendments for adequate soil productivity. The soil reaction was slightly acidic with pH of 6.10. This slightly acidic nature could be attributed to low rainfall and high cropping intensity (Onyekwere *et al.*, 2008). The organic carbon was low 12.1 gkg^{-1} (Federal Department of Agriculture and Land Resources, 1990). This could be as a result of low natural organic matter returns and other human factors such as crop removal and burning. The total nitrogen was very low with the value of 1.62 gkg^{-1}. This low nitrogen content was a reflection of the organic carbon content in the soils (Onyekwere *et al.*, 2003). The exchangeable Mg and Ca were moderate with the values of 2.40 $Cmol(+)kg^{-1}$ and 3.60 $Cmol(+)kg^{-1}$, respectively (Federal Department of Agriculture and Land Resources, 1990). The exchangeable K was very low with value of 0.117 $Cmol(+)kg^{-1}$ which was below 0.20 $Cmol(+)kg^{-1}$ regarded as the critical limit of exchangeable K in the soils (Onyekwere *et al.*, 2001). The exchangeable Na and exchangeable acidity were also low with the values of 0.189 $Cmol(+)kg^{-1}$ and 0.24 $Cmol(+)kg^{-1}$, respectively. Available P was high with the value of 33.60 $mgkg^{-1}$.

4.2 Chemical Properties of Biochar

Biochar recorded higher values of the various parameters studied than soil (Tables 1 and 2). For instance, the pH of soil was slightly acidic (6.10) while that of biochar was very strongly alkaline 9.64. The higher values of these parameters in biochar compared to soil justified the use of biochar as soil amendment.

4.3 Soil Chemical Properties

Soil post harvesting content of pH, total N, OC, available P, Ca, Mg, K, Na and exchangeable acidity were significant higher in biochar applied plots compared to control (Tables 3 and 4). Similarly, the higher the quantity of biochar applied, the higher the magnitude of pH, total N, OC, available P, Ca, Mg, K, Na and exchangeable acidity observed. This is attributed to the large carbon component of biochar and the elemental composition of biochar which consists of different minerals such as Nitrogen, Phosphorus, exchangeable bases etc (Lehmann, *et al*, 2009). The study disagreed with (Laird *et al*., 2010) that application of biochar to the soil decreased pH but however, agreed with them that application of biochar to the soil increased soil phosphorus. Yuan and Xu (2011) showed that pH increased significantly with increasing application rates of biochar, reflecting the fact that the liming potential increased with increasing application rates of biochar. Brockhoff *et al.* (2010) in their study on physical and mineral nutrition properties of sand-base turf grass root zones amended with biochar reported an increase in potassium content of biochar amended soil relative to unamended soil which is also in support of this study. Similarly, Major *et al*., (2010b) in their study of maize yield and nutrition during 4 years after biochar application to a colombia savannah Oxisol observed an increase in exchangeable acidity in biochar amended soil relative to unamended soil. Jien and Wang (2013) studying the effects of biochar on soil properties and erosion potential in a highly weathered soil also confirmed the effectiveness of biochar in improving the physical and chemical properties of soil that is highly weathered and their results indicated that soil pH, cation exchange capacity, and base saturation increased significantly after the addition of biochar and that the improvements in soil characteristics varied with variations in the amount of biochar added to the soil.

4.4 Carbon Storage

Result of the study showed significant higher carbon storage in plots treated with biochar relative to control. Also, there was an increase in carbon storage with an increase in quantity of biochar applied (Table 5). This is because biochar amendment enhances microbial activity and accelerated the decomposition of soil organic carbon (Wardle *et al.*, 2008). Major *et al.* (2010b) found that biochar from old mango (Mangifera indica L.) trees applied to a savanna Oxisol in Colombia at the rate of 23.2 tha^{-1} induced greater CO_2 emissions, which was attributed to the enhanced below-ground net primary productivity under biochar addition. The significant increases in C among all soil types and application methods make biochar a valuable C sequestration tool, as evident by its long residence times in many ecosystems (Rackham 1980; Lehmann et al. 2006).

4.5 Maize Growth and Grain Yield

Table 6 shows that biochar application significantly increased maize height and maize grain yield relative to control. Results of the study also showed that the higher the biochar application, the higher the maize height and maize grain yield recorded. The increased maize yield in biochar amended soil could be attributed to increased nutrient availability (Chan *et al.*, 2007, 2008; Zhang *et al*., 2010). Biochar amendments have been shown to increase crop productivity by improving the physical and chemical properties of cultivated soils (Asai *et al.*, 2009; Major *et al.*, 2010). High levels of soil organic carbon accumulation due to biochar amendment could enhance N efficiency and increase crop productivity (Pan et al., 2009).

V. CONCLUSION

Results of this study have shown a significant improvement in soil chemical properties, carbon storage and crop performances as a result of using biochar as soil amendment. This improvement increased with an increase in the quantity of biochar applied which made it possible for biochar at 15 t ha^{-1} to record the highest improvement in soil chemical properties, carbon storage and crop performances. This study suggests that biochar at rates higher than 15t ha^{-1} should be used in another study to ascertain when the trend will reverse as to know the recommended rate of biochar application for optimum crop productivity.

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