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Effect of Biochar on Selected Soil Physical Properties and Maize Yield in an Ultisol in Abakaliki Southeastern Nigeria

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This study was carried at Teaching and Research Farm of Faculty of Agriculture and Natural Resources Management, Ebonyi State University, Abakaliki to evaluate the effect of biochar on selected soil physical properties and agronomic parameters in an Ultisoil in Abakaliki, Southeastern Nigeria. The experiment was laid out in randomized complete block design (RCBD). Treatments were biochar at 0 tha^{-1} (Control), 5 tha^{-1}, 10 tha^{-1} and 15 tha^{-1} 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 soil particle size distribution, bulk density, total porosity, dispersion ratio, saturated hydraulic conductivity, aggregate stability, mean weight diameter and moisture content while agronomic parameters measured were maize height, leaf area index and maize grain yield. Results of the study showed that biochar amended plots had significant ($P < 0.05$) higher aggregate stability, maize height, leaf area index and maize grain yield than control. Results also showed non-significant ($P < 0.05$) changes in bulk density, total porosity, dispersion ratio, saturated hydraulic conductivity, mean weight diameter and moisture content among different rates of biochar application. Also, there was an increase in the magnitude of the parameters with an increase in the rate of biochar applied. This study recommended that biochar should be used as soil amendments to increase soil productivity.

Keywords: Agronomic parameters, Biochar, Physical properties, Soil productivity

Novelty Satement

Biochar has not been fully utilized by the farmers in the study area for improving soil productivity. The results showed that biochar can improve soil physical properties and increase maize yield. We found that increasing the rate of biochar application resulted to higher improvement in soil physical properties and crop yield.

INTRODUCTION

Biochar, a by-product of the pyrolysis process, is biomass-derived black carbon intended for use as a soil amendment. It is analogous to charcoal manufactured through traditional or modern pyrolysis methods, and to black carbon found naturally in fire-ecosystems. Biochar is used as a soil amendment to improve soil nutrient status, C storage and/or filtration of percolating soil water (Lehmann and Joseph 2009). However, research has shown that application of biochar to soil may be more desirable as it can increase soil organic carbon (SOC), improve the supply of nutrients to plants and therefore, enhance plant growth and soil physical, chemical, and biological properties (Glaser *et al.,* 2002; Lehmann *et al*., 2006; Rondon *et al*. 2007).

Biochar can be used as a soil amendment to improve soil quality and crop productivity in a variety of soils (Blackwell *et al.* 2009). This has been demonstrated primarily in soils that are highly weathered or degraded through agricultural activities (Glaser *et al.* 2002; Kimetu *et al.,* 2008). Liang *et al.* (2010) reported high stabilization of organic material added to soils from a tropical environment containing aged charcoal. According to Glaser *et al*. (2002) improvements in soil water retention by biochar additions may only be expected in coarse-textured soils or soils with large amounts of macropores and that a large amount of biochar may be needed to apply to the soil before its water retention increases. Soil moisture retention improvement is an indirect result of alterations in soil aggregation and structure after biochar application (Brodowski *et al*. 2006). Biochar can affect soil aggregation through interactions with soil organic matter, minerals, and microorganisms; however, the surface charge characteristics and their development over time determine the long-term effect on soil aggregation. Piccolo and Mbagwu (1990); Piccolo *et al.* (1996) and Mbagwu and Piccolo (1997) have proved that increased surface area, porosity, and lower bulk density in mineral soil with biochar can alter water retention, aggregation, and decrease soil erosion. Incorporation of biochar into soil modifies soil physical properties such as soil structure, bulk density, porosity, texture, and particle size distribution. This affects important soil function such as water holding capacity, aeration and plant growth (Alkinson, *et al.,* 2010). Biochar can alleviate soil compaction by decreasing bulk density, which increase porosity and accentuates favourable soil processes (Laird *et al.* 2010). Application of biochar as a soil amendment reduces tensile strength and penetration resistance (Chan *et al.,* 2007; 2008; Busscher *et al.,* 2010). In addition to improve soil mechanical properties, it also increase water infiltration rate, reduces runoff and decreases erosion (Asai *et al.,* 2009). There is also improvement in water retention characteristics including available water capacity and field capacity (Lehmann *et al.* 2006; Chan *et al.* 2007; Asai *et al.,* 2009; Chan and Xu, 2009; Laird *et al.,* 2010; Brockehff *et al.,* 2010). Biochar reduces saturated hydraulic conductivity in coarse textured soil and increases hydraulic conductivity in heavy textured soil by improving macro pores (Brockhoff *et al.* 2010).

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The main objective of this study is to determine the effect of biochar on soil physical properties, maize leaf area index and maize grain yield in an Ultisoil in Abakaliki, Southeastern Nigeria.

MATERIALS AND METHODS

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. The area is characterized by high rainfall and high temperature which ranged between 1800mm – 2000mm and 21^0C – 29^0C, respectively. The relative humidity of the area 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).

MATERIALS

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

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.

Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with five replications and four treatments. A total of 20 plots each measuring 3 m X 3 m (9 m^2) were used for the experiment. Plots were separated by buffer of 0.5 m and each replicate was 1 m apart. Treatments were biochars at 0, 5, 10 and 15tha^{-1}. Treatments were uniformly 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 one plant/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. Also, the crop was raised under rainfed system.

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 the determination of soil particle size distribution. Also, core soil samples of 167 cm^2 were collected from three observational points at the depth of 6cm in each plot at 90 days after planting (DAP) and used for determination of soil physical properties.

Laboratory Analysis

Soil sample was analyzed using the following method.
Bulk density (Bd): Bulk density was determined using core method (Blake and Hartage, 1986).
Total porosity (Tp): This was calculated from bulk density using the formular:
Tp = 100(1 – Bd/Pd); where Bd = Bulk density, Pd = Particles density and Pd is assumed to be 2.65gcm^{-3} (Obi, 2000).
Hydraulic conductivity: This was determined as described by Landon (1991).
Mean weight diameter: This was determined by calculation as described by Kemper and Rosenau (1986).
Aggregate stability: This was determined using the wet sieving method described by Kemper and Rosenau (1986).
Moisture content: This was determined by calculation as outlined by Obi (2000).
Particle size distribution: Particle size distribution was determined from initial soil sample using the Bouyoucous hydrometer method as described by Gee and Bauder (1986).
Dispersion ratio: This was determined as outlined by Nkidi-Kizza *et al.,* (1984).

Agronomic Parameters

The following agronomic parameters were taken.
Plant height: Seven maize plants per plot were sampled for plant height at 90 days after planting (DAP). Plant height was measured from the ground surface to the tip of the plant using a metre rule.
Leaf Area Index: Leaf area index was determined by multiplying length and width of the leaves and constant (0.70)
Crop yield: At maturity 7 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 was weighed and then converted to its hectare equivalent.

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., 2008).

RESULTS

Soil Particle Distribution

Results of soil particle distribution are as shown in Table 1. The textural class of the studied soil was sandy loam comprising of 98, 182 and 720 gkg^{-1} of clay, silt and sand.

Effect of Biochar on Soil Bulk Density, Total Porosity, Dispersion ratio and Hydraulic conductivity

The effect of biochar on soil bulk density, total porosity, dispersion ratio and hydraulic conductivity is presented in Table 2. The application of biochar shows non-significant ($P < 0.05$) change in soil bulk density, total porosity, dispersion ratio and hydraulic conductivity among the different rates of treatments application. However, total porosity and hydraulic conductivity observed in the biochar treated plots were higher than that of control. The order of increase in total porosity and hydraulic conductivity varies with an increase in the quantity of biochar application. On the other hand dispersion ratio of 0.72 was recorded for each rate of biochar application. Control recorded the highest soil bulk density of 1.45 gcm^{-3} while that of biochar treated plots ranged between 1.35 – 1.38 gcm^{-3}.

Table 1: Soil Particle Distribution

Soil properties	Values
Clay	98 gkg^{-1}
Silt	182 gkg^{-1}
Sand	720 gkg^{-1}
Textural class	Sandy loam

Table 2: Effect of Biochar on Soil Bulk Density, Total Porosity, Dispersal ratio and Hydraulic conductivity

Treatments	Bulk Density (gcm^{-3})	Total Porosity (%)	Dispersal Ratio	Hydraulic Conductivity ($cmhr^{-1}$)
T_1	1.45	45.28	0.72	42.69
T_2	1.38	47.92	0.72	42.75
T_3	1.37	48.30	0.72	53.11
T_4	1.35	49.06	0.72	54.61
F-LSD (0.05)	NS	NS	NS	NS

Where: T_1 = 0 tha^{-1} (Control), T_2 = 5 tha^{-1}, T_3 = 10 tha^{-1} andT_4 = 15 tha^{-1}

Effect of Biochar on Soil Aggregate Stability, Mean Weight Diameter and Moisture Content.

Results of effect of biochar on soil aggregate stability, mean weight diameter and moisture content are presented in Table 3. Aggregate stability significantly ($P < 0.05$) increased with amendment of T_1 (3.41), T_2 (4.81), T_3 (7.04) and T_4 (8.32). The highest aggregate stability observed in T_4 was higher than aggregate stability in control by 144%. On other hand there was non-significant ($P < 0.05$) changes in mean weight diameter and moisture content observed in the various treatment observed. Lowest mean weight diameter of 2.60 mm was observed in control whereas that of biochar treated plots ranged between 2.68 – 2.79 mm. The order of increase in moisture content was $T_3 > T_2 > T_1 > T_4$.

Effect of Bioachar on Maize Height, Leaf Area Index and Maize Grain Yield

Table 4 shows the effect of biochar on maize height, leaf area index and maize grain yield. The application of biochar significantly ($P < 0.05$) increase maize height, leaf area index and maize grain yield relative to control. Also, the higher the quantity of biochar applied, the higher the maize height, leaf area index and maize grain yield observed. The lowest maize height of 1.10 m was observed in control. The observed maize height in control was lower than maize height in T_2, T_3 and T_4 by 26, 41 and 74%, respectively. The order of increase in leaf area index was $T_4 > T_3 > T_2 > T_1$. Control recorded the lowest maize grain yield of 0.51 tha^{-1} which was lower than maize grain yield in T_2, T_3 and T_4 by 4, 18 and 31, respectively.

DISCUSSION

Soil Physical Properties

The result of soil particle distribution showed that the soil studied is sandy loam comprising of clay (98 gkg^{-1}), silt (182 gkg^{-1}) and sand (720 gkg-^{1}). Sandy loam is highly permeable and allows large quantities of leachates to pass through it (Anikwe and Nwobodo, 2002). This high permeability has

Table 3: Effect of Biochar on Soil Aggregate Stability, Mean Weight Diameter and Moisture

Treatments	Aggregate Stability (%)	Mean weight Diameter (mm)	Moisture Content (%)
T_1	3.41	2.60	24.00
T_2	4.81	2.68	24.55
T_3	7.04	2.72	24.56
T_4	8.32	2.79	21.85
FLSD (0.05)	1.09	NS	NS

Where: T_1 = 0 tha^{-1} (Control), T_2 = 5 tha^{-1}, T_3 = 10 tha^{-1} andT_4 = 15 tha^{-1}

Table 4: Effect of Biochar on Plant Height, Leaf Area Index and Grain Yield

Treatments	Maize height (m)	Leaf area index	Grain yield tha^{-1}
T_1	1.10	2.83	0.51
T_2	1.39	3.68	0.53
T_3	1.55	4.58	0.60
T_4	1.91	5.27	0.67
FLSD (0.05)	0.29	0.91	0.34

Where: T_1 = 0 tha^{-1} (Control), T_2 = 5 tha^{-1}, T_3 = 10 tha^{-1} andT_4 = 15 tha^{-1}

made the soil to be low in plant nutrients (Enwezor *et al*., 1988, Asadu and Akamigbo, 1990, Nnabude and Mbagwu 1999 and Ogbodo and Nnabude, 2004). Hence, the need for biochar amendments which acoording to Alkinson *et al.* (2010) improves soil physical properties such as soil structure, bulk density, porosity, texture, and particle size distribution and affects important soil function such as water holding capacity, aeration and plant growth. The application of biochar shows non-significant ($P < 0.05$) change in soil bulk density, total porosity, dispersion ratio and hydraulic conductivity among the different treatment rates (Table 2). Although, total porosity and hydraulic conductivity observed in the biochar treated plots were higher than that of control while bulk density observed in treated plots were lower than that of control. The order of increase in total porosity and hydraulic conductivity and decrease in bulk density varies with an increase in the quantity of biochar application. Jein and Wang (2013) studying the effects of biochar on soil properties and erosion of potential in a highly weathered soil indicated a significant decrease in bulk density and an increase in porosity and saturated hydraulic conductivity. The decrease in bulk density and increase in total porosity in the biochar amended soils might be caused by physical dilution effects which agreed with Busscher *et al.* (2011) who indicated that increasing total organic carbon by the addition of organic amendments in soils could significantly decrease bulk density. Furthermore, the decrease in bulk density of the biochar-amended soils appears to have also been the result of alteration of soil aggregate sizes, as shown by Tejada and Gonzalez (2007). Table 3 also, showed a significant ($P < 0.05$) increase in aggregate stability and non-significant ($P < 0.05$) increase in mean weight diameter and moisture content observed in the various rates of biochar applied. The incorporated biochar could function as a binding agent that connects soil micro-aggregates to form macro-aggregates. The oxidized biochar surface, which included hydroxyl groups and carboxylic groups, could adsorb soil particles and clays to form macro-aggregates (Jein and Wang, 2013). Also, Asai et al. (2009) indicated that the incorporation of biochar into crop-growing soils changed the pore-size distribution, which increased water permeability. The increase in mean weight diameter of the soil aggregates of the biochar-amended soils could be attributed to an increase in the amount of oxidized functional groups after mineralization of the biochar (Cheng et al., 2006), which facilitated flocculation of both the soil particles and the biochar. Liu et al. (2012) showed that soil aggregate sizes and stability could be significantly increased through the addition of biochar to the soil, especially for the silt loam soil and is in support of the current study.

Agronomic Parameter

Table 4 showed that the application of biochar significantly ($P < 0.05$) increased maize plant height, leaf area index and maize grain yield relative to control and that, the maize height, leaf area index and maize grain yield obtained increased with an increase in the biochar rate application. The improvement in agronomic parameters may be attributed to the fact that the incorporation of biochar into crop-growing soils changed the pore-size distribution (Asai *et al.,* 2009) thereby making the pores to serve as a shield by protecting biochar decomposing microbes from predation and desiccation while the organic matter adsorbed to biochar provides energy and mineral nutrient requirements for crop growth (Warnock *et al.*, 2007; Saito and Muramoto, 2002). Similarly, according to Blackwell *et al.* (2009) biochar can be used as a soil amendment to improve soil quality and crop productivity in a variety of soils. This has been supported by studies carried out in soils that are highly weathered or degraded through agricultural activities (Glaser et al. 2002; Kimetu et al. 2008).

CONCLUSION

This study showed the effect of biochar application in selected soil physical properties and maize yield in an Ultisol in Southeastern Nigeria. Results show that the effect of biochar was higher on crop parameters than soil physical properties as significant ($P < 0.05$) changes were observed in all the crop parameters studied. On the other hand, there were non- significant ($P < 0.05$) changes in most of the soil physical parameters studied relative to control. This may be attributed from the fact that the study lasted for a year and the biochar rates used were lower than 15 tha^{-1}. Therefore, higher rates of biochar application and more long-term researches are needed to facilitate the understanding of effects of biochar on soil physical properties as it is envisage that such research will indicate more significant effects of biochar on soil physical properties.

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