EFFECTS OF BIOCHAR AND INORGANIC FERTILIZER ON SELECTED SOIL PROPERTIES AND MAIZE PERFORMANCE AT MINNA, NIGERIA.

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Abstract
A field trial was carried out at the Teaching and Research Farm of the Federal University of Technology, Minna to investigate the impact of biochar in combination with inorganic fertilizer on selected soil properties and maize performance. Biochar used in the study was produced from camel foot (*Piliostigma reticulatum*) and bilinga (*Nauclea* spp). The trial was a 3 x 4 factorial experiment arranged in a randomized complete block design (RCBD) with three levels of biochar (0, 2.5 and 5 t/ha) and four levels of nitrogen (0, 30,60,120 kg N/ha) with urea as the source replicated three times. Data collected were subjected to analysis of variance (ANOVA) and significant means were separated using Least Significant Difference (LSD). Results showed that biochar application significantly ($p \leq 0.05$) reduced bulk densitywhen compared with the control. Inorganic fertilizer had no significant ($p \geq 0.05$) effect on this soil property. Application of biochar, inorganic fertilizer and their interaction had no significant ($p \geq 0.05$) effect on mean weight diameter and organic carbon. Height, stover and grain yields of maize were significantly($p \leq 0.05$) increased by biochar and inorganic fertilizer application. Interaction between biochar and inorganic fertilizer also had significant effect on these parameters. From the results, combination of biochar and inorganic fertilizer could greatly increase maize yield and reduce fertilizer use in Nigeria.

Introduction

In order to overcome the challenge of food insecurity in Nigeria, farmers have resorted to intensively cultivating their lands year after year and this has led to a decline in soil quality through nutrient mining and loss of organic matter (Oshunsanya and Aliku, 2015). With continuous cultivation, soil physical properties and productivity decline due to decrease in organic matter content (as a result of rapid mineralization) andbreakdown of surface aggregates (Oguike and Mbagwu, 2009). Organic manure has been advocated to alleviate the problem of soil quality decline (Yusuf *et al*., 2016). Studies have shown that organic manure improve nutrient and water use efficiency of crops, soil structure, cation exchange capacity and the buffering capacity of low activity clay soil (Omotayo and Chukwuka, 2009; Agbede and Adekiya, 2015). However, for continued productivity, organic matter has to be applied every cropping season because of high rate of mineralization which leads to loss of nutrients contained in them.

Biochar provides a new approach to mitigating the challenge of declining soil productivity associated with tropical soils and also providing a means of storing carbon in the soil thereby reducing global warming. Biochar refers to the carbon-rich solid substance produced from pyrolysis (heating in the presence of limited or absence of oxygen to a temperature of about 400^0C) of organic materials (Chan *et al*., 2008). Biochar as a soil amendment, improves soil productivity (Lehman and Joseph, 2009), provides a sustainable method of managing crop and animal wastes from agriculture which otherwise causes environmental pollution (Matteson and Jenkins, 2007) at the same time sequestering carbon thereby mitigating climate change (Lehman *et al*., 2006). The renewed interest in biochar started as a resultof biochar-type substances which explained the high organic carbon and the sustained productivity of the Amazonian Dark Earth known as *Terra Preta de Indio*. Secondly, recent research results have shown that biochar is more stable than any other soil amendment and it increases nutrient availability beyond fertilizer effects (Lehman and Joseph, 2009), the high porosity of biochar improves soil structure and water holding capacity of soils (Cheng *et al*., 2008). Available data on the effects of biochar on soil properties in Nigeria are few and conflicting. Biochar has been reported to decrease bulk density (Laird *et al*., 2010; Jones *et al*., 2010; Chen *et al*., 2011; Mukherjee *et al*., 2014).Also, amending soil, with biochar had varied effects on aggregate stability. Some authors reported significant increase in mean weight diameter (Major *et al*., 2012; Jien and Wang, 2013; Ouyang *et al*., 2013; Njoku *et al*., 2015; Ma *et al*., 2016) while others reported that amending soil with biochar had no effects whatsoever on aggregation (Busscher *et al*., 2011; Liu *et al*., 2012 Mukherjee *et al*., 2014; Hardie *et al*., 2014).

Soils in Minna are characterized by coarse texture, low organic carbon, CEC, total nitrogen and available phosphorus ranges from low to medium (Lawal *et al*., 2013; Afolabi *et al*., 2014 Lawal *et al*., 2014). The effects these properties are evident in declining soil quality which has impacted crop yield negatively. In order to mitigate this decline in soil quality and crop yield, integrated use of organic manure and inorganic fertilizer has been advocated. This has however, had limited success because of its loss through rapid mineralization and the need to apply same every year prior to cropping the land (Omotayo and Chukwuka, 2009; Agbede and Adekiya, 2015). Studies have shown that biochar is recalcitrant and does not require annual application (Lehaman and Joseph, 2009). Over the years, Nigerian government has popularized the use of inorganic fertilizers in order to improve crop yield but the risk of soil degradation from its continuous use, increasing cost of procuring the commodity and late supply are some of the constraints encountered by farmers (Chude *et al*., 2012). This study seeks to evaluate the impact of biochar (as a replacement for organic manure) on selected soil properties which may in turn lead to a reduction in inorganic fertilizer use for maize production in Nigeria. Specific objectives were: to evaluate the effect of biochar in combination with inorganic fertilizer on (i) soil bulk density, total porosity, mean weight diameter, organic carbon and effective cation exchange capacity. (ii) height, stover and grain yields of maize.

Materials and Methods

Site Description

The study was carried out at the Teaching and Research Farm of the School of Agriculture and Agricultural Technology, Federal University of Technology, Minna in 2017 cropping season. The study area is located between latitude 9^0 31′ 1.16″ and longitude 6^0 26′ 30.07″ at elevation of 216 m above sea level in the Southern Guinea savanna zone of Nigeria. The climate is sub-humid tropical with an average temperature of about 33^0C and average annual rainfall of 1338 mm that lasts from April to October with the dry season lasting for about five months.

Biochar Production

The biochar used in this study was produced using camel foot (*Piliostigma reticulatum*) and bilinga (*Nauclea* spp). These shrubs were sourced from adjoining fallow lands.. The feedstock (which included roots, stems and leaves of the plants) was sundried for about one week and later converted to biochar by heating using the traditional earthen mound kiln method (without energy capture) in which the earth was used to regulate the amount of oxygen at an average temperature of about 400^0C within the kiln.

Experimental Design

The trial was a 3 x 4 factorial experiment arranged in a randomized complete block design (RCBD) with three levels of biochar (0, 2.5 and 5 t/ha) and four levels of nitrogen (0, 30, 60, 120 kg N/ha) using urea as the source. This was replicated three times. A total of thirty-six plots, each measuring 4 x 4 m were used for the experiment. Plots were separated by a buffer of 1 m and the replicates were 3 m apart.

Cultural Practices

Biochar was broadcast on each plot and manually incorporated into the topsoil using a hoe two weeks before seed planting. Urea was applied by side placement at 2 and 6 weeks after planting in split dose. Two maize seeds (Variety- Oba super II) were planted per hole at a depth of about 3 cm with inter row spacing of 75 cm while intra row spacing of 25 cm on ridges made manually. The seedlings were thinned to one plant per stand 2 weeks after planting. Weeding was carried out manually using hoe at 2 and 6 weeks after planting. There was no application of herbicides and pesticides to the plots. Also, the crop was raised under rainfed system and allowed to dry before it was harvested.

Soil Sampling and Preparation

Initial soil samples were collected randomly from the site at 0 – 15 cm depth before the experiment. The samples were thoroughly mixed to form a composite soil sample. From the composite sample, a sub-sample was taken and air-dried under a shed in a dust free environment. Air-dried samples were crushed gently using a porcelain mortar and pestle, and passed through 2 mm sieve. Also, some samples were passed through 0.5 mm sieve for organic carbon determination. After the study, disturbed and undisturbed samples were taken randomly from each plot.Undisturbed core samples were taken from three points within each plot while disturbed samples were taken from different points within a plot and bulked to form composite samples while.

Laboratory Analyses of Experimental Soil and Biochar

The undisturbed core samples were used to determine bulk density (Anderson and Ingram, 1993).

The air-dried soil samples were analyzed for particle size distribution using hydrometer method. pH was determined in a soil-water ratio of 1:2, total nitrogen was determined by the Kjeldahl method.Available phosphorus was determined by Bray P-1 method.Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were determined following IITA (1982) routine procedures.Effective cation exchange capacity (ECEC) was estimated by summation of total exchangeable bases and total exchangeable acidity. Organic carbon was determined using Walkley-Black wet oxidation method(Nelson and Sommers, 1982).Mean weight diameter was determined using the wet-sieving method (Kemper and Rosenau, 1986). Mean Weight Diameter (MWD) was calculated using the relationship below:

$$MWD = \sum_{i=1}^{n} d_i \times p_i$$

d_i = mean diameter of an aggregate fraction of the sieve (Average of the mesh size that retain the fraction and the one on top)

p_i = proportion of aggregate in each fraction(ratio of a weight of a given fraction to total weight of sample)

Chemical properties of the biochar that were determined include pH, organic carbon, total nitrogen, ECEC, available phosphorus, potassium, magnesium and calcium.

Agronomic Parameters

The following agronomic data were collected

Plant Height

Ten maize plants per plot were sampled for plant height at 16 weeks after planting. Plant height was measured from ground surface to the tip of the plant using a measuring tape.

Stover Yield

Stover yield was determined after harvesting the crop. The leaves, stem, husk and cobs after shelling were weighed and expressed in t/ha.

Grain Yield

At maturity, cobs from the inner rows were harvested, sun-dried (13 – 14% moisture content), threshed and grains weighed per plot. These weights were expressed in t/ha.

Statistical Analysis

Statistical analysis of the data was carried out using the General Linear Model of SAS software for randomized complete block (RCBD) while significant treatments means were separated using Least Significant Difference (LSD).

Results and Discussion

Initial Soil Characteristics of soil

The initial soil characteristics of the study area are presented in Table 4.1. The textural class is sandy loam. The pH (in water) was strongly acidic (5.4). Organic carbon and total nitrogen (3.80 and 0.11 g/kg) were very low. ECEC (10.09 cmol/kg) and available phosphorus (6.89 mg/kg) were low. Sodium, Potassium, magnesium and calcium (ranged from 0.26 – 6.00 cmol/kg) were low to high.These properties characterize a typical savanna soil as recorded by other authors (Lawal *et al*., 2013; Afolabi *et al*., 2014 Lawal *et al*., 2014)

Table 4.1: Initial Soil Characteristics

Soil Properties	Values
Particle Size Distribution (g/kg)	
Sand	792
Silt	33
Clay	175
Texture	Sandy Loam
pH(H_2O)[a]	5.4
Organic Carbon (g/kg)	3.8
Total Nitrogen (g/kg)	0.11
Available Phosphorus (mg/kg)	6.89
Exchangeable Bases (cmol/kg)	
Ca	6
Mg	2.53
K	0.35
Na	0.26
Exchangeable Acidity (cmol/kg)	1.02
ECEC (cmol/kg)	10.09

Chemical properties of Biochar Used in the Study

The chemical properties of biochar used in the study are presented in Table 4.2. The pH (in water) was strongly alkaline (8.30). Values for N and P (0.90 and 1.70 %), were low while K, Mg and Ca (2.74, 3.08 and 3.54 %) were high. ECEC (96.09 cmol/kg) and organic carbon (63.5 %) were high to very high.

A unique characteristic of biochar is high C: N ratio. Biochar used in this study has a C: N ratio of 70.5 which is consistent with those produced by other authors. Fagbenro *et al*. (2013) produced biochar from saw dust with C: N of 80.4. Similarly, Fagbenro *et al*. (2018) produced biochar from Gliricidia with C: N of 86.7.

Table 4.2: Chemical Properties of Biochar Used

Property	Value
pH(H_2O)[a]	8.30
Organic Carbon (%)	63.5
Total Nitrogen (%)	0.90
Phosphorus (%)	1.70
K (%)	2.74
Ca (%)	3.54
Mg (%)	3.08
ECEC (cmol/kg)	96.09

[a]Measured in 1:2 soil: water ratio

Effects of Biochar on Selected Soil Properties

The effects of biochar in combination with inorganic fertilizer on selected soil properties are presented in table 4.3. Application of biochar resulted in significant ($p \leq 0.05$) changes in bulk density and total porosity. Bulk densitydecreased with increasing rate of biochar application. This decrease may have arisen from the oxidation of labile humic materials contained in the biochar. Humic materials have been reported to reduce bulk density, improve soil structure, aeration, enhance water infiltration and retention as well as increase microbial population in the soil (Githinji, 2013; Hardie *et al.*, 2014; Gumus and Seker, 2015).

However, biochar application had no significant ($p \geq 0.05$) effect on MWD. This might be due to the low quantity of biochar applied. Other authors have reported significant increase in MWD when higher rates of biochar were applied (Jien and Wang, 2013; Ouyang *et al.*, 2013; Ma *et al.*, 2016). Njoku *et al.* (2015) explained that the non-significant effect of biochar on MWD might have resulted from the low quantity of biochar applied and the short duration of the study (one season).Similarly, biochar application had no significant ($p \geq 0.05$) effect organic carbon.This might have been due to the low quantity of biochar applied. This is consistent with the reports of Ndor *et al.* (2015) and Fagbenro *et al.* (2018). They both reported that organic carbon content at 5 t/ha biochar application rate was statistically at par with that of control.

Table 4.3: Main Effects and Interactions of Biochar and Inorganic Fertilizer on Selected Soil Properties

Factors and Levels	Bulk Density (g/cm^3)	MWD	Organic Carbon (g/kg)
Biochar(t/ha)			
0	1.51a	0.83	6.08
2.5	1.47b	0.85	7.05
5.0	1.35c	0.86	7.72
LSD	0.024	NS	N S
Fertilizer (kg N/ha)			
0	1.45	0.83	6.36
30	1.44	0.85	6.93
60	1.42	0.86	6.94
120	1.43	0.86	7.59
LSD	N S	N S	N S
Interaction			
Biochar*Fertilizer	N S	NS	N S

Means in a column within a treatment and followed by different letter are significantlydifferent at$p \leq 0.05$. LSD = Least Significant Difference, NS = Not Significant, MWD = mean weight diameter.

Effects of Biochar on Height, Stover and Grain Yields of Maize

The effects of biochar in combination with inorganic fertilizer on height, stover and grain yields of maize are presented in Table 4.4. Biochar application had significant ($p \leq 0.05$) effect on height, stover and grain yields of maize. These parameters increased proportional to the rate of biochar application.Studies by some authors also reported positive crop response to biochar application (Chan *et al.*, 2008; Zhang *et* *al*., 2011; Njoku *et al*., 2015; Fagbenro *et al*., 2018). This may be due to slow biotic and abiotic mineralization of the biochars, the high specific surface, and large amount of chemically reactive sites, high porosity of the biochars and the beneficial effects of biochars on soil microbe (Fagbenro *et al*., 2018). However, negative yield responses of crops have also been reported (Chan *et al*., 2007; Asai *et al*., 2009). Crop response to biochar amendment depends on the chemical and physical properties of the biochar, crop type, soil and climatic conditions (Zhang *et al*., 2011; Fagbenro *et al*., 2018).Similarly, Table 4.4 shows that application of inorganic fertilizer alone produced significant effect on height, stover and grain yields of maize. The beneficial effect of inorganic fertilizer on maize growth may be due to the positive effect of nitrogen that was contained in the fertilizer which resulted in the vigorous growth and grain yield of maize (Asai *et al*., 2009; Zhang *et al*., 2011; Fagbenro *et al*., 2018). Inorganic fertilizers provided the easiest and fastest methods of correcting nutrient deficiency because they contain plant nutrients in concentrated form (Chude *et al*., 2012). Interaction between biochar and inorganic fertilizer had significant ($p \leq 0.05$) effect on height, stover and grain yields of maize.

Table 4.4: Main Effects and Interactions of Biochar and Inorganic Fertilizer on Height, Stover and Grain Yields of Maize

Factors and Levels	Plant Height (cm)	Stover Yield (t/ha)	Grain Yield (t/ha)
Biochar (t/ha)			
0	179.50c	2.56c	1.02c
2.5	187.18b	3.55b	1.29b
5.0	236.67a	3.72a	3.02a
LSD	4.22	0.03	0.04
Fertilizer (kg N/ha)			
0	166.89d	2.51d	1.12d
30	187.56c	2.66c	1.48c
60	199.11b	3.42b	1.96b
120	249.89a	4.50a	2.54a
LSD	4.87	0.04	0.05
Interaction			
Biochar*Fertilizer	*	*	*

Means in a column within a treatment followed by different letter are significantly different at 5% level of probability. LSD = Least Significant Difference, * = significant at $p \leq 0.05$.

Conclusion

Application of biochar produced from *Piliostigma reticulatum* and *Nauclea* spp significantly ($p \leq 0.05$) reduced bulk density but did not alter MWD and organic carbon significantly. Biochar, inorganic fertilizer as well as their interaction significantly enhanced the height, stover and grain yield of maize. The data obtained in this study showed that application of biochar in combination with inorganic fertilizer will not only increase maize yield in the short term but also maintain soil quality for continued productivity over the long term as obtained in *Terra Petra* soils. In this study, 5 t/ha of biochar was the maximum rate of application. Higher rates of application should be investigated. More research should be carried out to study the effects of biochar on the chemical and biological properties of the soil. This will enable proper planning and maintenance of soil productivity.

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