EFFECT OF TWO BIOCHAR TYPES AND INORGANIC FERTILIZER ON SOIL CHEMICAL PROPERTIES AND GROWTH OF MAIZE (ZEA MAYS L.)

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ABSTRACT

Two pot experiments were conducted to evaluate the influence of saw dust biochar (SB), gliricidia biochar (GB) and NPK 15:15:15 inorganic fertilizer on soil chemical properties and maize (Zea mays L.) grown in an Oxisol at Iwo in South-western Nigeria. Saw dust biochar and GB were applied at four levels of 0, 5, 10, 20 t C ha-1 and NPK inorganic fertilizer also at four levels of 0, 22.5, 45, 90 kg N ha-1. Application of saw dust biochar (SB) and gliricidia biochar (GB) showed a small but statistically significant (p>0.05) increase in most of the soil chemical parameters of the soil - total N, %OC, available P, exchangeable cations (K, Ca, and Mg) and effective cation exchange capacity (ECEC). But soil pH was increased only at GB application levels of 10 and 20 t C ha-1 while Na did not appear to be affected. These soil parameters in most cases increased with application rates. Application of inorganic fertilizer, however, generally resulted in decrease of the soil chemical variables. The application of either SB, GB or NPK fertilizer significantly stimulated maize development with respect to plant height, stem diameter and dry matter production which generally increased with the application rates of the amendments. Although the biochar-inorganic fertilizer interactions were not statistically significant for any of the plant parameters assessed, it was concluded that complementary use of biochars and inorganic fertilizers for crop production remains a research issue that is worthy of further investigation especially in the field.

Keywords: Oxisol, Saw Dust, Gliricidia, Biochar, Zea Mays.

Introduction

The inherent capacity of the highly weathered tropical soils, including those in Nigeria, to provide plant nutrients and support optimum crop production is very limited (Babalola, 2002). Reported research results in Nigeria have indicated that it is the combination of inorganic fertilizers and organic inputs that gives optimum crop production (Lombin et al., 1991). However, inorganic fertilizers, besides their high cost which makes them not to be affordable to resource-poor peasant farmers in the country, their continuous application without a corresponding organic input has been reported to deplete native soil organic matter (Madeley, 1990). Organic materials, apart from the fact that adequate quantity may not be available on every peasant farmer's farm (Aduayi, 1991), they decompose very fast under the prevailing tropical conditions that their benefits are often short-lived (Jenkinson and Ayanaba, 1977; Bol et.al., 2000). As a result, sustained maintenance of adequate organic matter in the tropical soils is still a challenge to both the peasant farmers and the soil scientists working in the tropical region (Agboola and Fagbenro, 1985) hence the sustained inefficient fallowing system in the tropics.

One emerging and highly promising practice for sustaining soil organic matter and sustainable agriculture is biochar technology (Zheng, et al., 2010). Biochar is a term used to designate a carbon-rich solid product obtained when a biomass is heated in a closed container under the atmosphere of little or no oxygen (Lehmann and Joseph, 2009a).

Review of literature has shown that biochar is stable in the soil for several hundred years because of its aromatic structure which makes it recalcitrant to microbial degradation (McLaughlin et al., 2009). In addition, it contains variable amount of plant nutrients, depending on the feedstock and processing temperature, and organic polymers. All these properties make biochar an effective organic soil conditioner and a driver of nutrient transformation in the soil (Glasser et.al., 2000a; 2002a; Gundale DeLuca, 2006).

However, the majority of biochar research in the world (69.0 ± 2.9 %) was associated with highly developed countries (Mehmood et al., 2017). According to Mehmood and others (2017), less developed countries are eager to improve soil fertility and agricultural productivity which may require transfer and/or translation of biochar knowledge acquired in highly developed countries to less developed countries. In our opinion, this may not work perfectly well because the multi-beneficial effectiveness of biochar can be site-specific with respect to soil types, plant species and climatic conditions (Fagbenro, 2017). It is therefore crucial to encourage systematic sustainable biochar research especially in the Sub-Saharan African countries that have the most depleted soils in the world (IFDC, 2012).

This study was therefore conducted to investigate the effect of saw dust biochar and gliricidia biochar in combination with NPK (15:15:15) inorganic fertilizer on soil chemical properties and growth of maize, using a sandy Oxisol under greenhouse condition. Our aim is to develop biochar-based farming systems in Nigeria that will eliminate slash and burn form of agriculture and improve the quality of our soils for sustainable crop production and yield so as to reduce poverty among our rural farming families.

Materials and Methods

Two pot experiments were conducted at Iwo, latitude 07^0 39^1N and longitude 04^0 09^1E, South-western Nigeria, to investigate the influence of saw dust biochar (SB) and Gliricidia biochar (GB) in combination with NPK 15:15:15 inorganic fertilizer on soil chemical properties and growth of maize (Zea mays L.). A sandy Oxisol was used. Bulk surface soil (0-30cm) was air-dried, crushed, sieved (>2 mm) and analysed for key physico-chemical properties (Table 1). The soil reaction (pH) was determined potentiometrically in soil: water ratio of 1:2 using a Kent model 720 glass electrode (pH) meter. Organic carbon was determined using the Walkley-Black (1934) chromic acid digestion procedure. Total N was determined using the method of Keeney and Bremner (1966) while soil available P (Mehlich), K, Ca. Mg, and Na were determined following IITA (1982b) routine procedures. The effective cation exchange capacity (ECEC) was determined by adding the values of all the cations and the exchangeable aluminum together. The water holding capacity of the soil was determined to be 44.5%.

Saw dust feedstock, which was a mixture of wood waste sawn from indigenous hardwoods of *Triplochiton sceleroxylon, Milletia excelcia.* Terminalia species and *Acacia siame*, was collected from Oluwaseyi saw mill within Iwo municipality where it was constituting an environmental nuisance. *Gliricidia sepium* feedstock was from *Gliricidia sepium*, a nitrogen fixing tree species that grows widely on fallow land in Nigeria and which does not appear to have any higher net resource value other than to be converted to biochar. The feedstocks were converted separately to biochars by heating using the traditional earthen mound kiln method in which earth was used as a shield against O_2. Average temperature within the kiln was 400^0C. Key chemical properties of the two biochars were determined using routine procedures (IITA, 1982b) while their humic substances content was exhaustively extracted with 0.1MNaOH solvent and fractionated according to Fagbenro (1988). These properties are presented in Table 2.

Table 1: Key properties of soil (0-30 cm) sample used for the Pot Experiments

Property	Value
Texture	Sand (g/kg) 872
	Slit (g/kg) 40
	Clay (g/kg) 88
pH($H_2$0)	6.2
Total N (g/kg)	2.3
Organic C (g/kg)	3.9
Av. P (g/kg)	8.5
K (cmol/kg)	0.24
Na (cmol/kg)	0.60
Mg (cmol/kg)	0.58
Ca (cmol/kg)	1.50
Cu (mg/kg)	2.36
Zn (mg/kg)	5.69
Fe (mg/kg)	78.3
Mn (mg/kg)	79.60

In a factorial combination, four levels of SB or GB, namely 0, 5, 10 and 20 t C ha^{-1} and four levels of NPK inorganic fertilizer, 0, 22.5, 45 and 90 kg N ha^{-1}, were added to 5 kg samples of soil on dry weight basis and were put in 10-L black plastic pots. The mixtures in the pots were moistened to 50% water holding capacity and left for 7 days to equilibrate.

Four seeds of “Apron plus” treated maize variety TZSR-W were sown per pot and thinned to one plant per pot two weeks after germination. The treatments were replicated three times.

At the end of 13 weeks of growth, the plants were measured for height , stem diameter, number of leaves produced and then harvested Fresh shoot and root were weighed and oven-dried separately at 70^{0}C to constant weight to determine dry matter yield.

After harvesting, the post-harvest soil from each pot was air-dried, mixed thoroughly, and crushed gently. A subsample was ground to pass through a 2-mm sieve. The <2-mm samples were then analysed for pH, N, OC, P, K, Ca, Mg, Na and ECEC using methods described above.

Statistical analysis

Analysis of variance was carried out at 5% probability level on data collected. Duncan's Multiple Range Test was used for means separation where significant effects were obtained.

Table 2: Key Properties of Saw dust Biochar (SB) and Gliricidia Biochar (GB) Used for the Pot Experiments

	Saw Dust Biochar (SB)	Gliricidia Biochar (GB)
pH(H_20)	8.1	8.5
pH ($CaCl_2$)	7.8	8.3
NO_3-N (g/kg)	1.7	1.0
NH_4-N (g/kg)	0.8	0.4
Total org. C (g/kg)	908.7	982.8
Total N (g/kg)	11.3	10.3
C: N ratio	80.4	86.7
Total P (g/kg)	3.8	2.8
K (g/kg)	5.4	4.0
Mg (g/kg)	1.9	1.4
Ca (g/kg)	1.5	1.7
Na (g/kg)	1.8	1.4
S (g/kg)	0.9	0.7
Ash (g/kg)	38.0	37.2
Humic acid (HA) g/kg	80.9	92.2
Fulvic acid (FA) g/kg)	49.0	41.2
HA:FA	1.65	2.24
Mn (mg/kg)	17.6	9.4
Cu (mg/kg)	2.4	9.8
Zn (mg/kg)	479.8	14.7
Fe(mg/kg)	23.1	9.4
Exch. Acidity (cmol/kg)	0.65	0.25
CEC (cmol/kg)	106.38	45.38

Results and Discussion

Effects of Biochars and Inorganic Fertilizer on Soil Chemical Properties

Application of saw dust biochar (SB) and gliricidia biochar (GB) showed a small but statistically significant ($p>0.05$) increase in most of the soil chemical parameters of the soil assessed - total N, %OC, available P, exchangeable cations (K, Ca, and Mg) and effective cation exchange capacity (ECEC). But soil pH was increased only at GB application levels of 10 and 20 t C ha^{-1} while Na did not appear to be affected (Table 3). These soil parameters in most cases increased with application rates. Application of inorganic fertilizer, however, generally resulted in decrease of the soil chemical variables.

Table 3: Selected Properties of Post-Harvest Soil Sample.

Treatment	pH H_2O	%N	%OC	Mehlich P mg/kg	Ca	Mg	K	Na	ECEC
					←		cmol/kg		→
No fertilizer & no biochar	6.15b	0.028c	0.360b	5.81bc	1.48c	0.54d	0.08ab	0.08	2.165c
22.5 kg N/ha	5.80c	0.028c	0.360b	6.45b	1.38c	0.53de	0.06bc	0.08	2.045c
45 kg N/ha	5.85c	0.025d	0.350b	6.16b	1.34c	0.49e	0.05c	0.08	1.965d
90 kg N/ha	5.80c	0.024d	0.315b	8.23a	1.42c	0.53de	0.06bc	0.08	2.080c
5 t C/ha SB	6.05b	0.027c	0.365b	4.26c	1. 63b	0.63b	0.07b	0.08	2.395b
5 t C/ha GB	6.00b	0.028c	0.360b	4.52c	1.45c	0.59c	0.06bc	0.08	2.175b
10 t C/ha SB	6.05b	0.032b	0.425a	5.00bc	1.73b	0.71a	0.09a	0.08	2.610b
10 t C/ha GB	6.40a	0.032b	0.445a	5.47bc	1.72b	0.66b	0.09a	0.07	2.540b
20 t C/ha SB	6.15b	0.034a	0.430a	5.52bc	1.81ab	0.72a	0.09a	0.08	2.700a
20 t C/ha GB	6.50a	0.032b	0.450a	5.47bc	1.94a	0.76a	0.10a	0.08	2.880a

In this and other tables, values followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test. SB=Saw dust biochar, GB= Gliricidia biochar.

Increase in soil chemical properties following application of SB and GB in the sandy Oxisol indicated the potential of biochars in enhancing soil fertility and health and that fairly large amount of N, carbon and exchangeable cations were accumulated through biochar application (Chan et al., 2007b; Zheng et al., 2010). The observed increase in soil ECEC with increase in biochar application rates could be due to the appreciable amount of basic cations in the biochars. Increase in soil reaction (pH) as a result of GB application rates could also be attributed to the basic cations contained in the biochar. Our result is similar to those reported in the literature (Chan et al., 2007b & 2008; Glaser et al., 2002a; Zheng et al., 2010; Zwieten et al., 2010).

Reduction in soil pH with increase in NPK inorganic fertilizer application rates could be attributed to reduction in organic carbon which has buffering effect on soil pH. It could also be due to the presence of nitrate and ammonium ions in the applied fertilizer which have been reported to cause soil acidification. Significant reduction in soil OC following NPK application is likely to be as a result of increased activity of soil microorganisms in response to the applied inorganic fertilizer which probably resulted in increased mineralization of native soil organic matter (Madeley, 1990). Reduction in the soil N and the exchangeable cations when inorganic fertilizer was applied could be due to the maize uptake of the nutrients present in the soil and those contained in the applied NPK fertilizer. There was also the possibility of leaching of the remaining nutrients in the applied fertilizer as the experimental soil was low in organic carbon (Table 1) which could reduce or prevent nutrient leaching.

Main Effect of NPK Inorganic Fertilizer on Maize Plant

Table 4 gives the result of performance of maize plants when fertilized with NPK inorganic fertilizer alone. The maize plants responded positively with the plants grown in treatments having fertilizer performing significantly better than those in the non-treated control. Tallest plant (136.5cm) was observed at 90kg N ha^{-1} application level which was at par with application rates of 22.5 (120.7cm) and 45kg N ha^{-1} (125.6cm). Shortest plant (103.0cm) was observed in the non-treated control. Similar trend was observed for stem diameter but the highest dry matter yield (77.2g) was recorded for plant grown in the treatment that received the highest level of fertilizer which was significantly ($p>0.05$) higher than those of other treatments having fertilizer addition. The higher the application rates of the fertilizer, the more beneficial its effect on the plant parameters except for the number of leaves which was not significantly affected.

The beneficial effect of NPK inorganic fertilizer on maize growth could be attributed to the positive effect of N, and possibly to P and K also contained in the fertilizer, on vigorous vegetative growth of plant (Khan et al., 2008; Arif et al., 2012). Lower growth of maize plant in the control could be due to less available N and other nutrients for optimum plant growth (Khan et al., 2008). This result is also confirmed by the findings of Delate and Camberdella (2004) and Asai and others (2009).

Table 4: Main Effect of NPK 15:15:15 Inorganic Fertilizer on 13 – Week Maize Grown in an Oxisol.

Kg N ha^{-1}	HT(cm)	SD (mm)	LF	DM(g)
0	103.0b	14.9b	14a	51.0c
22.5	120.7a	17.1a	13a	64.0b
45	125.6a	17.3a	13a	67.5b
90	136.5a	18.3a	14a	77.2a

Foot note: HT= Height, SD= Stem diameter, LF= Leaf number, DM= Dry matter yield.

Main Effect of Saw Dust Biochar and Gliricidia Biochar on Maize Plant

In the absence of NPK fertilizer, data regarding effect of saw dust biochar (SB) and Gliricidia biochar (GB) on maize plant are reported in Table 5. The response trend of maize plant to GB amendment was similar to that of NPK fertilizer (Table 4) being highly significant in its effect on height and stem diameter growth of the plant whereas the effect of SB on these two plant parameters was not significant when compared to the control, confirming that all biochars are not created the same (McLaughlin et al., 2009). Both biochars significantly ($p>0.05$) increased dry matter (DM) yield of maize even at the lowest level of application. The yield increased with increasing rate of application. This trend was similar to that of NPK fertilizer (Table 4). The highest dry matter yield for SB was 74.8 g while that of GB was 77.9 g, both at the highest application level of 20 t C ha^{-1}. Student t-test showed no significant difference between the effects of the two biochar types on maize dry matter yield.

The positive response of maize plant to sole application of SB and GB in this study confirms the reported stimulating effect of biochars on maize growth (Yamato et al., 2006; Chan et al., 2008; Zhang et al., 2011). The fact that the highest dry matter yield of maize was obtained at the highest biochar application level confirms the results reported by Chan and others (2008), Karhu and others (2011) and Fagbenro and others (2012b) that effect of biochar on plant productivity increased with the quantity added to soil. The positive effect of the two biochars on maize plant may be due to a number of factors which include gradual abiotic and biotic oxidative release of nutrients and humic substances contained in the biochars (Fagbenro and Agboola, 1993; Arif et al., 2012; Fagbenro et al., 2012b), the high specific surface area, large amount of chemically reactive sites and high porosity of biochars (Petter and Madari, 2012), the nutrient-transforming property of biochars in the soil system (Gundale and DeLuca, 2006) and the beneficial effect of biochars on soil water holding capacity and on a variety of agriculturally important soil micro-organisms (Ogawa et al. 1983).

Table 5: Main Effect of Saw Dust Biochar and Gliricidia Biochar on 13 – Week Maize Grown in an Oxisol.

Biochar (t C ha^{-1})	SB		GB	DM(g)
	DM(g)	HT(cm)	SD(mm)	
0	51.0c	103.0c	14.9b	51.0c
5	59.2b	95.7c	15.6b	62.1b
10	62.1b	120.7b	17.4a	64.0b
20	74.8b	140.9a	18.8a	77.9a

Interaction Effect of NPK Inorganic Fertilizer and the Two Biochar Types on Maize Plant

Analysis of variance data on the interaction effect of SB and GB with NPK 15:15:15 inorganic fertilizer on maize plant is presented in Tables 6a and 6b. The combination of inorganic fertilizer with either of the two biochars did not significantly ($p>0.05$) affect the plant parameters assessed although the higher the biochar application rate, the higher the maize parameter (data not shown).

Table 6a: Analysis of Variance Table for the Interaction of Saw dust Biochar with NPK 15:15:15 Inorganic Fertilizer on 13 – Week Maize Grown in an Oxisol.

Parameter	Df	SS	MS	F-value	Pr>F
Height	9	1224.99	136.11	0.61ns	0.7772

Stem diameter	9	29.04	3.23	1.11ns	0.3812
No. of leaf	9	0.193	0.021	1.03ns	0.4418
Dry matter	9	1174.36	130.48	1.69ns	0.1329

Foot note: In this and other tables, Ns = Not significant at 5% probability level.

Table 6b: Analysis of variance table for the interaction of gliricidia bio char with NPK 15:15;15 Fertilizer on 13-Week Maize Grown in an Oxisol.

Parameter	Df	SS	MS	F-value	Pr > f
Height	9	866.74	96.30	0.27ns	0.9738
Stem diameter	9	14.51	1.61	0.57ns	0.8097
No. of leaf	9	0.266	0.030	1.09ns	0.3967
Dry matter	9	750.47	83.89	1.09ns	0.3968

Conclusion

Application of saw dust biochar (SB) and gliricidia biochar (GB) improved significantly the chemical properties of the experimental soil while simultaneously enhancing the growth of maize plant. This result suggests that part of the main mechanisms behind the reported positive effects of biochar application to soils on plant productivity may be a combined effect of soil nutrient release following biochar application and liming property of biochar. The technology of using biochar as soil conditioner and fertilizer in the Nigerian sandy Oxisol is therefore a promising future alternative to the production of crops such as maize. Although sole application of inorganic fertilizer also enhanced maize growth, its application resulted in the impoverishment of soil chemical properties which implies that sole application of inorganic fertilizer for crop production may not be sustainable. Considering the data obtained in this study, we conclude that the effect of sole application of either SB or GB on plant growth is comparable to that of NPK 15:15:15 inorganic fertilizer applied alone. Although the combination of NPK fertilizer and any of the two biochar types did not significantly affect the growth of maize plant, complementary use of biochars and inorganic fertilizers at varying application rates for crop production is still a highly relevant research issue that is worthy of further exploring particularly in field experiments.

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