Ameliorative Effect of Biochar Application on Selected Chemical Properties of Acidic Soil

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Abstract

This research was conducted at the screenhouse of Biological Science, Usmanu Danfodiyo University, Sokoto, Nigeria, to determine the ameliorative effect of biochar application on selected chemical properties of acidic soil. The acidic soil used for the experiment was collected from Centre for Agricultural and Pastoral Research (CAPAR), Dabagi, Usmanu Danfodiyo University, Sokoto while the biochar used was obtained from Labana Rice Mill, Brinin-Kebbi, Kebbi State. The biochar was applied at rate of 0, 10, 20, 30, 40, 50, 60 and 70 t/ha. The experiment was laid out in a completely randomized design (CRD) and replicated three times. Data were collected on some soil chemical properties and were subjected to Analysis of Variance (ANOVA) and significant means were separated using Duncan's Multiple Range Test at 5% level of significance. The results showed that successive increment in biochar rates virtually increased all the soil chemical properties tested for, with 70 t/ha of biochar rate significantly ($p \leq 0.05$) higher than the other biochar rates. A field trial of long term experiment with lower doses of biochar rates supplemented with inorganic fertilizer should be conducted in order to have more feasible doses of biochar in the remediation of acidic soil.

Keywords: acidic soil, biochar, chemical properties, remediation, screenhouse

Introduction

Soil acidity is a serious challenge facing agricultural producers in tropical and subtropical regions and limits legume productivity (Bordeleau and Prevost, 1994). The high concentration of H^+ ions causes the solubility of Al, Mn, and Fe, which becomes strong inhibitors of symbiosis (Whelan and Alexander, 1986) and nutrients deficiency. Some soils can be naturally acidic (low pH) while others are much more alkaline. The soil with lower pH (highly acidic) has detrimental effect on soil chemical properties as well as the growth and yields of the crops that are sensitive to acidic condition. In acidic soils the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium, organic carbon among others is reduced and may be insoluble (Gazey and Davies, 2009). Hence, soil acidity could lead to the deterioration of the soil and nutrient deficiency among others (Owolabi et al., 2003).

Several soil liming and amendment materials were widely used to increase soil pH including dolomite, calcite, and lime and which in turn reduce exchangeable aluminium, iron, and hydronium in the soil. The above mentioned acidic soil remediating materials are relatively expensive to afford by the subsistence farmers. However, there has been increased interest on alternative liming agents with multiple benefits such as pyrolytic biochars which can be used to improve soil fertility and to store carbon (C) in the soil (Steiner et al., 2007; Nguyen & Lehmann, 2009; Yuan & Xu, 2011). Biochar is thermally-decomposed (pyrolysis) in a low or no oxygen environment (Gaskin et al., 2008) and deliberately applied to the soil to improve its properties (Lehmann and Joseph, 2009) and soil pH (Xu et al., 2006). Sohi et al., (2010) reported an increase in sorption capacity for nutrients by acidic soil due to application of biochar while Van Zwieten et al. (2009) reported a reduction in the exchangeable acidity as a result of biochar application.

However, information on the effect of biochar on the chemical properties of acidic soil in the study area is not adequate and therefore there is the need to check if biochar could be used to raise the soil pH as well as improving its chemical properties. This research aims to evaluate the ameliorative effect of biochar on some chemical properties of acidic soil of Dabagi, Sokoto State.

Materials and Methods

Study area

The research was conducted at the Screenhouse of the Department of Biological Science, Usmanu Danfodiyo University, Sokoto, Nigeria. Sokoto State is located in North-western part of Nigeria, near the confluence of the Sokoto River and Rima River, situated between latitudes 11° 13′ to 13° 50′ N and longitudes 4° and 6° E having altitude of 350m above sea level (Sokoto State Tourist Guide, 2010). The climate of Sokoto State is hot, semi-arid, with long dry season characterized by cool dry air during harmattan around November to February and hot dry air during hot season from March to May, with short rainy season ranging from June to October with average of 630 mm, relative humidity range from 26-29%. Minimum temperature ranges between 19º C and 27º C and maximum temperature ranges from 30 - 40º C and wind direction generally North-westerly in the dry season and South-westerly in the wet season and wind speed range between 1.7 and 4.0 m/s (Jibrillah et al., 2018).

Source of biochar

The biochar was collected from Labana Rice Mill, Birnin-Kebbi, Kebbi State. The biochar was produced using rice husk as the feedstock by pyrolysis for 40-60 minutes at temperature range of about 250°C–300°C. Biochar was crushed and passed through a 2 mm sieve before chemical characterization. The nutrients composition of biochar analysis includes; pH, organic carbon, available P, total N, cation exchangeable capacity (CEC) and exchangeable bases (Mg, K, Na and Ca).

Experimental design and layout

The biochar was incorporated at the rates of 0, 10, 20, 30, 40, 50, 60 and 70 t/ha which is equivalent to 0, 25, 50, 75, 100, 125, 150 and 175g of biochar in to 5kg of acidic top soil collected from Centre for Agricultural and Pastoral Research (CAPAR), Dabagi Area, Sokoto State at a depth of 0-15 cm. SAMNUT-24 was used as test crop and the experiment was laid out in a Completely Randomized Design (CRD) and replicated three times in the screenhouse.

Soil sampling and laboratory analysis

The soil was sampled before the experiment and also from each bucket in the screenhouse after harvest and chemical characteristics of the soil were determined using standard methods. The soil pH was determined using glass electrode pH meter (McLean, 1971). Soil organic carbon was determined using oxidation method of Nelson and Sommers (1982). Total nitrogen was determined by Micro Kjeldahl digestion method (Bremmer and Mulvaney, 1982). Available phosphorus was determined using bray-1 method (Bray and Kurtz, 1945). Calcium (Ca) and magnesium (Mg) were determined using EDTA titration method while potassium (K) and sodium (Na), in the extract were read using flame photometer. The cation exchange capacity of the soil samples was determined using normal neutral ammonium acetate (Davis and Freitas, 1970).

Data analysis

The data obtained was subjected to Analysis of Variance (ANOVA) and the significance differences among means were separated using Duncan's Multiple Range Test (DMRT) at 5% level of significance.

Results and Discursion

Chemical properties of soil and biochar used for the study

The pre-sowing analyses of the soil and biochar used for this experiment were presented in Table 1. The soil pH was 5.02 and was rated as strongly acidic while that of biochar was 8.14 and was rated as moderately alkaline (Soil survey division staff, 2017). The available phosphorus of the soil was 1.14 mg/kg while that of biochar was 1.53 mg/kg and both were rated as very low according to Landon (1984). The percentage organic carbon of the soil was 0.42% and was rated as low while that of biochar was 7.78% and was rated as medium (Landon, 1984). The total nitrogen of the soil was 0.025% and is rated as low while that of biochar was 0.280% and was rated as medium (Enweazor et al., 1989). The cation exchange capacity (CEC) of the soil was 1.92 cmol/kg and was rated as low while that of biochar was 10.16 cmol/kg and was rated as medium (Esu, 1991).

The exchangeable bases of the soil viz.; Ca was 0.55 cmol/kg and was rated as low (0-2 cmol/kg), Mg was 0.50 cmol/kg and was rated as medium (0.3-1.0ccmol/kg), K was 0.10 cmol/kg and was rated as low (0-0.15 cmol/kg) and Na was 0.17 cmol/kg and was rated as medium (0.1-0.3 cmol/kg) (Enweazor et al., 1989). Similarly, the exchangeable bases of the biochar viz.; Ca was 0.50 cmol/kg and was rated as low (0-2 cmol/kg), Mg was 0.85 cmol/kg and was rated as medium (0.3-1.0 cmol/kg), K was 5.83 cmol/kg and was rated as high (>0.3

cmol/kg) and Na was 2.18 cmol/kg and was rated as high (>0.3 cmol/kg) (Enweazor et al., 1989).

Table 1. *Chemical properties of soil and biochar used for the study*

Properties	Biochar	Soil
pH	8.14	5.2
Organic Carbon (%)	7.78	0.42
Phosphorus (mg/kg)	1.53	1.14
Total Nitrogen (%)	0.28	0.025
CEC (cmol/kg)	10.16	1.92
Exchangeable bases (cmol/kg)		
Magnesium	0.85	0.5
Calcium	0.5	0.55
Sodium	0.18	0.17
Potasium	5.83	0.1

Effect of biochar on soil pH, organic carbon, total nitrogen and available phosphorus (P) at 9 and 15 WAA (weeks after amendment with biochar).

The soil pH after biochar amendment in the soils was presented in Table 2. At 9 weeks after amendment with biochar (WAA) the biochar rates of 50, 60 and 70 t/ha recorded significantly ($p \leq 0.05$) higher values of soil pH when compare to 0, 20 and 30 t/ha of biochar rates. However, 50, 60 and 70 t/ha were statistically comparable with 40 t/ha at 9 WAA. Similarly, at 15 WAA the biochar rates of 50, 60 and 70 t/ha were also significantly ($p \leq 0.05$) higher when compare to 0, 10 and 20 t/ha but statistically comparable with 30 and 40 t/ha. The soil pH increased with increasing quantity of biochar and this could be as a result of alkaline nature of rice husk biochar. Similar result was found in the work done by Glaser *et al*. (2002); Lehmann and Rondon (2006), who reported that biochar, can serve as a liming agent, resulting in increased pH of the soil.

Significant differences were observed among biochar application rates on available P where 60 and 70 t/ha biochar rates recorded significantly ($p \leq 0.05$) higher available P than 0, 10 and 20 t/ha, but statistically similar to 30, 40, and 50t/ha of biochar rates at 9 WAA. Similarly, at 15 WAA all the biochar rates were significantly ($p \leq 0.05$) higher in available P than control (0 t/ha). This might be attributed to the ability of biochar pH to break the complexes of Al and Fe in soil and thereby releasing more phosphorus. This is in conformity with the research of Prasad (1992) who reported that soil available P increased significantly under liming due to lowering P fixation by other elements (Al, Mn, and Fe). Sood and Bhardwaj (1992) and Rahman et al., (2001) have also reported that soil available P was higher under limed over the none-limed plots.

Similarly, the percentage organic carbon increased with increasing amount of biochar rates with 70 t/ha significantly ($p \leq 0.05$) higher in organic carbon content when compared to other biochar rates though comparable with 60 t/ha at 9 WAA. But at 15 WAA, the biochar rates of 40, 50, 60 and 70 t/ha were significantly ($p \leq 0.05$) higher than 0, 10 and 20t/ha rate of biochar application but statistically similar with 30 t/ha.

The increase observed in the OC could be as a result of the organic carbon content in the biochar which is capable of increasing the soil organic carbon after amendment. Similar result was reported by Nigussie et al., (2012); Lehmann (2007); Zhang et al., (2012).

At 9 WAA, the total nitrogen followed the same trend as that of organic carbon with 70 t/ha significantly ($p \leq 0.05$) higher than other biochar rates though statistically similar to 60 t/ha of biochar rates. At 15 WAA, the biochar rates 60 and 70 t/ha were significantly ($p \leq 0.05$) higher than other biochar rates of application but statistically the same with 50 t/ha. Liang *et al*. (2006) stated in his research that the total nitrogen also increased with the successive increment in the rate of biochar and this could be due to decomposition which might have occurred when biochar is added to soil, which could induce net immobilization of inorganic N already present in the soil solution.

Effect of biochar on exchangeable bases and cation exchange capacity (CEC) at 9 and 15 WAA (Weeks After Amendment with biochar)

Table 3 indicated that addition of biochar increased all the exchangeable bases (Ca, Mg, Na and K) and cation exchange capacity of the soil at each successive increase in the rate of biochar application. At 9 WAA, no significant difference was observed among the biochar application rates in calcium (Ca) which could be as result of slow mineralization of biochar. But at 15 WAA, the biochar rates of 60 and 70 t/ha recorded significantly ($p \leq 0.05$) higher in calcium than other biochar application rates. 70 t/ha of biochar rate recorded significantly ($p \leq 0.05$) higher values of Mg when compared to other biochar rates and statistically comparable with 20, 30, 40, 50 and 60 t/ha at 9 WAA. But at 15 WAA, the biochar rates of 40, 50, and 70 t/ha were significantly ($p \leq 0.05$) higher than other biochar rates but statistically comparable with 30 and 60 t/ha.

There were significant differences among biochar rates in Na at 9 WAA, where 60 and 70 t/ha recorded significantly ($p \leq 0.05$) higher values of Na than other biochar rates. At 15 WAA, the biochar rate of 70 t/ha was significantly ($p \leq 0.05$) higher than 0, 10, and 20, and 30 t/ha though statistically comparable with 40, 50 and 60 t/ha. Potassium increased with increasing rate of biochar with 70 t/ha producing significantly ($p \leq 0.05$) higher than 0, 10 and 20 t/ha though comparable with 30, 40, 50 and 60 t/ha at 9 WAA. However, at 15 WAA there were no significant differences among the biochar rates in the amount of potassium.

Table 2. *Soil pH, organic carbon, total nitrogen and available phosphorus (P) at 9 and 15 WAA.*

	Soil pH		AP		OC %		TN	
Biochar rates (t/ha)	WAA 9	15	WAA 9	15	WAA 9	15	WAA 9	15
0	5. 01^{c}	5. 06^{d}	1.10^{c}	1.40^{b}	1.32^{c}	1.07^{c}	0.033^{f}	0.036^{d}
10	5.61^{bc}	5.73^{c}	1.40^{b}	1.98^{a}	1.34^{c}	1.26^{c}	0.035^{ef}	0.040^{cd}
20	5.70^{b}	6.06^{bc}	1.58^{b}	2.00^{a}	1.35^{c}	1.33^{bc}	0.037^{de}	0.043^{cd}
30	5.82^{b}	6.25^{abc}	1.63^{ab}	2.04^{a}	1.40^{c}	1.62^{ab}	0.041^{cd}	0.044^{cd}
40	5.95^{ab}	6.57^{ab}	1.66^{ab}	2.07^{a}	1.42^{c}	1.65^{a}	0.041^{cd}	0.048^{bc}
50	6.49^{a}	6.68^{a}	1.74^{ab}	2.11^{a}	1.52^{bc}	1.66^{a}	0.044^{bc}	0.055^{ab}
60	6.66^{a}	6.76^{a}	2.07^{a}	2.21^{a}	1.76^{ab}	1.82^{a}	0.046^{ab}	0.058^{a}
70	6.62^{a}	6.83^{a}	2.07^{a}	2.22^{a}	1.93^{a}	1.93^{a}	0.049^{a}	0.062^{a}
SE ±	0.13	0.13	0.05	0.06	0.08	0.06	0.001	0.002
LS ($p \leq 0.05$)	*	*	*	*	*	*	*	*

*OC = Organic carbon, TN = Total Nitrogen, AP = Available Phosphorous, Means within the same column with the same letters are not significantly different according to Duncan Multiple Range Test at ($p \leq 0.05$), SE = Standard error, * = Significant at ($p \leq 0.05$), WAA = Weeks After Amendment with biochar.*

Table 3. *Effect of biochar on Ca, Mg, Na, K and CEC at 9 and 15 WAA*

	Ca		Mg		Na		K		CEC	
Biochar rate (t/ha)	WAA 9	15	WAA 9	15	WAA 9	15	WAA 9	15	WAA 9	15
0	0.58	1.16^{d}	2.17^{c}	0.53^{c}	0.20^{c}	0.17^{c}	0.24^{c}	0.11	1.36^{d}	0.85^{d}
10	0.63	1.66^{cd}	3.00^{bc}	0.73^{c}	0.41^{bc}	0.19^{c}	0.30^{bc}	0.15	2.18^{c}	1.77^{cd}
20	0.90	2.23^{cd}	3.40^{abc}	1.07^{bc}	0.45^{bc}	0.20^{c}	0.31^{bc}	0.19	2.37^{c}	2.30^{cd}
30	0.98	2.37^{bcd}	3.50^{abc}	1.64^{ab}	0.51^{b}	0.26^{bc}	0.48^{abc}	0.21	3.07^{c}	2.90^{cd}
40	1.03	2.93^{bc}	3.83^{ab}	2.18^{a}	0.60^{b}	0.32^{abc}	0.47^{abc}	0.31	3.15^{ab}	3.19^{bc}
50	1.22	3.13^{b}	4.03^{ab}	2.05^{a}	0.93^{b}	0.45^{abc}	0.44^{abc}	0.41	3.58^{ab}	3.40^{bc}
60	1.40	4.80^{a}	4.13^{ab}	2.17^{ab}	0.94^{a}	0.52^{ab}	0.62^{ab}	1.10	3.73^{ab}	4.92^{ab}
70	1.72	5.23^{a}	4.67^{a}	2.40^{a}	0.94^{a}	0.60^{a}	0.68^{a}	1.15	3.82^{a}	6.68^{a}
SE ±	0.17	0.31	0.21	0.16	0.06	0.04	0.04	0.13	0.18	0.41
LS ($p \leq 0.05$)	Ns	*	*	*	*	*	*	ns	*	*

*Ca= Calcium, Mg = Magnesium, Na = Sodium, K = Potassium and CEC = Cation Exchange Capacity. Means within the same column with the same letters are not significantly different according to Duncan Multiple Range Test at (p> 0.05), SE = Standard error, ns = Not significant, * = Significant at (p≤0.05) and* WAA = Week After Amendment with biochar.

CEC followed the same pattern like other exchangeable bases by having 70 t/ha significantly higher than other application rates of biochar. At 9 WAA, the biochar rate of 70 t/ha was significantly ($p \leq 0.05$) higher in CEC than other biochar application rates but statistically similar to 40, 50 and 60 t/ha. Likewise at 15 WAA, 70 t/ha was rated to be significantly ($p \leq 0.05$) higher in CEC than other biochar rates but statistically the same with 60 t/ha.

Generally, the research indicated that biochar application to acidic soil increases the CEC and exchangeable bases, thereby improving the fertility of the soil and invariably increases the soil productivity. This result is in line with the previous researches by Yusif et al. (2016) who reported that biochar application have the potential to improve soil chemical properties. Rondon et al. (2007), Major et al. (2010), Liang et al. (2006), Agegnehu et al. (2016), Hardy et al. (2017) and Cheng et al. (2006) reported increased in CEC of soil amended with biochar.

Conclusion

The high rates of biochar have the potential to improve the soil chemical properties in acidic soil but may increase the amount of Na which is toxic to plant at a given quantity and can lead to sodicity of soil.

Recommendations

The biochar application rates of 50 t/ha was comparable with 60, and 70 t/ha in most cases and therefore be recommended for improvement of soil chemical properties of acidic soil. Biochar with low concentration of Na should be used to avoid toxicity and sodicity of soil. A field trial of long term experiment with lower doses of biochar rates supplemented with inorganic fertilizer should be conducted in order to have more feasible doses of biochar in the remediation of acidic soil.

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