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CHARACTERIZATION OF BIOCHAR PRODUCED FROM DIVERSE FEEDSTOCKS USED AS AMENDMENT ON ACIDIC ULTISOLS AT UMUDIKE, ABIA STATE.

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ABSTRACT

Biochar is used as a soil amendment to improve soil nutrients for crop production. The nutrient contents of biochar depend on the type of feedstock, pyrolysis types and temperature among others. In this study, it was hypothesized that biochar produced from different feedstock at the same temperature will have different effects on soil properties. To verify this, a pot experiement was set up at the Experimental Field of College of Crop and Soil Sciences of Michael Okpara University of Agriculture, to determine the effect of the biochar from twelve different feedstocks on soil chemical properties. The twelve types of biochar produced were from Bone, Cow dung, Mixed feedstock, Cocoa pod, Goat droppings others were Palm bunch, Pig waste, Poultry droppings, Saw dust, Rice mill husk, Ukpo shell (*Mucuna flagellipes*) and Wood shaving. These biochar types and a control without biochar served as the treatment, they were produced with the pyrolysis drum at the temperature of 450 ^{0}C. The treatments were applied at the rate of 3 t/ha (whose equivalent was 86 g) to 10 kg of soil weighed into pots and replicated 4 times in a Completely Randomized Design. The effects of the treatments were determined on the soil pH, exchangeable acidity, available phosphorus, total nitrogen. Others were organic carbon, exchangeable potassium, sodium, calcium and magnesium using the standard laboratory procedure. Biochar produced from mixed feedstock significantly ($p<0.05$) increased the soil pH from the pre-treatment pH value of 4.8 in water to 6.8. Soil total nitrogen was significantly increased to 0.15 % by the application of ukpo shell biochar while biochar produced from pig waste significantly reduced the soil exchangeable acidity to 0.50 cmolkg^{-1} from 1.96 cmolkg^{-1} of the pre-amended soil. The result showed that different feedstocks subjected to same pyrolysis temperature would produce biochar that will affect the soil chemical properties differently in a pot experiment. Further trail on the field with the treatments is recommended.

Keywords: Feedstock, chemical properties, biochar, characterization, temperature, pyrolysis.

INTRODUCTION

Biochar is a solid material produced during a process known as pyrolysis from the thermo-conversion of biomass under little or no oxygen for use in soils as an amendment, sequester carbon and off set carbon emission (Lehmann, *et al*., 2009, Bell and Worrall, 2011). The production of biochar through pyrolysis helps at reducing agricultural and other forms of organic wastes. These wastes not only occupy large land spaces but also constitute environmental nuisance. When they are converted into biochar, they are changed into a recalcitrant form, rendering the carbon in biochar more resistant to biodegradation (Lehmann *et al.,* 2009).

When biochar is applied to the soil, it increases the soil chemical properties. This is observed in the amount of nitrogen retention in the soil, increased organic carbon content, pH, cation exchange capacity, decreased exchangeable acidity, S, and Zn (Cheng *et al.*, 2008 and Novak *et al.*, 2009). The physical properties of the soil such as water holding capacity and surface area have been reported to be increased by the application of biochar (Laird *et al.*, 2010) while a decrease in soil bulk density and penetration resistance (Mankasingh *et al.,* 2011, Mukherjee and Lal, 2013) were observed when biochar was applied to the soil. Thus, the decrease in bulk density of biochar amended soil could be one of a good pointer to soil aggregation and aeration improvement. The higher the total porosity (micro- and macro-pores) the higher is soil physical quality because micropores are involved in molecular adsorption and transport (Mukherjee and Lal, 2013). When biochar is applied to the soil it improves soil fertility and at such add to soil essential nutrient for plant growth, increased microbiological activity, mycorrhizal associations and create a microhabitat in soil (Steiner *et al*., 2008 and Warnock *et al.,* 2007).Other important property of biochar is that when added to the soil, it helps to reduce the emission from biomass that would otherwise naturally degrade in the soils and liberate greenhouse gas (Winsely, 2007).

Biochar may be produced from various biomass feedstock materials at varying pyrolysis temperatures. The biomass feedstock types and temperature affect the nutrient composition of the biochar. Alburquerque, *et al.*,(2014) reported that biochar produced from wheat-straw and olive-tree-pruning increased dissolved organic C when added to the soil. Biochar produced from animal waste has higher levels of essential elements while that produced from woody or herbaceous biomass feedstock has less (Gaskin *et al.,* 2008; Mullen *et al.*, 2010; Uzoma *et al.,* 2011). Biochar produced from willow are more basic and had higher concentration of total Cu, Zn, Na, Ca, Mg, K, Sr, and B than those derived from pine (Nelissen *et al.,* 2014).

Presently, there is limited information available on whether biochar produced from different feedstock at the same temperature will have similar properties and will also affect the soil properties of the Tropics in the same way. Knowing the chemical constituent of the biochars produced from different feedstocks is very important as these materials would be used to produce agricultural crops that are consumable. The objective of this work therefore was to determine the chemical properties of biochar produced from different feedstock at the same temperature. The specific objective was to determine the effect of the biochar from twelve different feedstocks on soil chemical properties.

MATERIALS AND METHODS

A pot trial was conducted at the experimental field of College of Crop and Soil Sciences of Michael Okpara University of Agriculture Umudike (latitude 05°29`N and longitude 07°33`E). It has an elevation of 122 m above sea level, with mean rainfall of 2117 mm, distributed over nine to ten months in a bimodal rainfall pattern starting from April to July and August to October. The monthly minimum air temperature at Umudike ranged from 20 °C to

24 °C while the monthly maximum air temperature ranged from 28 °C to 35 °C. (Source: NRCRI Umudike Meteorological Station, 2014).

The soil used in the pot trial was classified as sandy loam in the textural class. It contained 92 gkg^{-1} clay, 168 gkg^{-1} silt and 740 gkg^{-1} sand and was collected in March 2014 from a depth of 0-20 cm layer at the latitude 05° 27`N and longitude 07° 32`E of the Eastern experimental farm of Michael Okpara University of Agriculture, Umudike. The soil samples were air- dried, passed through 5 mm sieve mesh and the pre-treatment analysis carried out (Table 1). Ten kilogram of the soil samples were weighed into 12 litre pots.

The treatment comprised of a control (no amendment) and twelve types of biochar produced from twelve feedstocks of agricultural wastes. They were passed through the pyrolysis drum at the temperature of 450 °C and afterwards characterized (Table 2) according to Biochar material test categories and characteristic of the IBI Biochar StandardsVersion 2.0 (2014). The chemical properties of biochar determined were those whose equipment for determination was available. The twelve biochar types were produced from Bone (BN), Cow dung (CD), Mixed feedstock (MFB), Cocoa pod (CP), Goat droppings (GD) others were Palm bunch (PB), Pig waste (PS), Poultry droppings (PT), Saw dust (SD), Rice mill husk (RMW), Ukpo shell (*Mucuna flagellipes*) (UKP)and Wood shaving (WS). The treatments were applied on dry basis at the rate of 3 t/kg whose equivalent was 86 g. They were randomly assigned to the pots and replicated four times in a Completely Randomized Design.

The following soil properties were determined; soil pH was determined with the pH meter in water in a1:2.5 soil to distilled water suspension (Thomas 1996); exchangeable acidity was determined by the method of Mclean (1982) using 1N KCI and titrating with 0.05 NaOH, Organic Carbon was determined by dichromate – oxidation method of Walkley and Black wet oxidation method as described by Nelson and Somner (1982). Available phosphorus was determined by Bray 2 method of Bray and Kurtz (1945) as outlined by Anderson and Ingram (1993). Total Nitrogen was determined by the micro-kjedhal method (Brookes *et al.,* 1985). Exchangeable Calcium, Magnesium, Sodium and Potassium were extracted with NH_4OAc buffered at pH 7.0 (Thomas, 1982). Calcium and magnesium were determined using Ethylene diamine tetra-acetic acid (EDTA) titration method while potassium and sodium were determined by flame Photometer (Rhoades, 1982). Effective cation exchange capacity (ECEC) was calculated as the summation of exchangeable basis (Ca, Mg, K & N) and exchangeable acidity expressed in cmolkg^{-1} (Tan 1996). Percentage base saturation was calculated by the summation of the TEB divided by the ECEC. Percentage Calcium Saturation was calculated by dividing the Exchangeable Calcium values by ECEC. Percentage Aluminum Saturation was calculated by dividing the Exchangeable Aluminum values by ECEC. Particle size analysis was done using the hydrometer method (Gee and Border, 1986).

The data generated were subjected to analysis of variance (ANOVA) for CRD while the means were separated using the Fisher's Least Significant difference (LSD).

RESULTS AND DISCUSSION

The properties of the soil before the application of the treatment (Table 1) showed that the soil was sandy loam in texture with 740 gkg^{-1} 168 gkg^{-1} and 92 gkg^{-1} of sand, silt and clay

Table 1: Physiochemical Properties of the Pre-treatment Soil

Properties	Values
Sand ($gkg-^1$)	740
Silt ($gkg-^1$)	168
Clay ($gkg-^1$)	92
Texture	SandyLoam
pH in H_2O	4.8
pH in KCl	3.9
Av. P ($mgkg^{-1}$)	12.4
N (%)	0.05
OC (%)	0.60
OM (%)	1.03
Ex.Ca ($cmolkg-^1$)	3.00
Ex.Mg ($cmolkg-^1$)	2.20
Ex.K ($cmolkg-^1$)	0.09
Ex.Na ($cmolkg-^1$)	0.10
Ex.Acidity ($cmolkg-^{1)}$	1.96
ECEC ($cmolkg-^1$)	7.41
%BS	73.48

Available P. denotes Available phosphorus; N = Nitrogen; OC = Organic carbon; OM – Organic matter; Ca = Calcium; Mg = Magnesium; K = Potassium; Na = Sodium; EA = Exchangeable acidity; BS = Base saturation; ECEC = Effective cation exchange capacity

respectively. It is acidic with a pH of 4.8, low in available phosphorus (12.4 $mgkg^{-1}$), total nitrogen (0.05 %) and organic carbon (0.60 %). These values and the others on Table 1 implies that the soil used for the trial was low in most of the nutrients which were beyond the critical levels (Enwezor *et al.*, 1989) and at such will lead to low fertility. The composition of the biochar (Table 2) revealed that Bone biochar (BN) had the highest values of pH (9.0) and calcium (10.30%) while the mixed feed stock biochar (MFB) had the highest values for phosphorus (75 %), nitrogen (0.21%), organic carbon (2.40 %) and potassium (0.47 %). Therefore the addition of the biochar amendment to the low fertile soil of the trial was appropriate looking at some of the chemical composition of the biochar (Table 2).

The result on Table 3, shows that all the treatment applied increased the soil pH more than the control however, Mixed feedstock biochar (MFB) significantly ($p<0.05$) increased the soil pH over all the treatments. All the treatments reduced the exchangeable acidity over the control while Pig waste biochar had the highest significant ($P<0.05$) reduction value of 0.50 $cmolkg^{-1}$. Exchangeable calcium was significantly ($p<0.05$) increased by the application of MFB. The percentage aluminum saturation was significantly ($p<0.05$) reduced by poultry droppings biochar and wood shavings biochar. The pots that received bone biochar had significantly ($p<0.05$) increased percentage calcium saturation over the other treatments.

It was observed from Table 4 that the pots that received UKP had significantly ($p<0.05$) in-

Table 2: The chemical composition of the applied biochar

Treatment	pH (H_2O)	P (%)	N (%)	OC (%)	Ca (%)	Mg (%)	K (%)	Na (%)
BN	9.0	65.0	0.17	2.00	10.30	5.40	0.34	0.47
CD	8.3	65.4	0.19	2.18	6.80	4.90	0.37	0.45
MFB	8.6	75.0	0.21	2.40	8.40	5.80	0.47	0.55
CP	8.3	67.0	0.18	2.08	7.20	5.30	0.29	1.44
GD	8.1	66.2	0.19	2.20	7.00	4.80	0.34	1.45
PB	8.2	66.5	0.18	2.03	6.80	5.10	0.30	1.45
PS	8.5	72.0	0.20	2.34	7.20	5.20	0.38	1.47
PT	8.5	73.4	0.20	2.35	7.80	5.40	0.39	0.51
RMW	7.8	60.6	0.17	2.01	7.40	5.30	0.31	0.42
SD	7.9	60.8	0.17	2.00	6.60	4.90	0.33	0.44
UKP	8.3	64.3	0.18	2.14	7.40	5.40	0.31	0.47
WS	7.8	60.6	0.17	2.01	7.40	5.20	0.33	0.44

BN denote Bone; CD denote Cow dung; MFB denote Mixed feedstock biochar; CP denote Cocoa pod; GD denoteGoat droppings; PB denote Palm bunch; PS denote Pig waste; PT denote Poultry droppings; SD denote Saw dust; RMW denote Rice mill husk; UKP denote Ukpo *(Mucuna Flagellipes)*; WS denote Wood shaving

creased value for soil total nitrogen. MFB had significantly ($p<0.05$) higher soil organic carbon and available phosphorus when compared to the other treatments applied.

In Table 5, the result obtained showed that the highest significant ($p<0.05$) value for exchangeable potassium was recorded in pots that received MFB, whereas the pots that received UKP had significantly ($p<0.05$) higher values of exchangeable magnesium than the other treatments. There were no significant differences among the treatments applied for exchangeable sodium. The treatment MFB had the highest significant ($p<0.05$) value for the percentage base saturation compared to the other treatments.

Mixed feedstock biochar (MFB) significantly increased the Effective Cation Exchange Capacity over the other treatments (Fig 1). The significant effect was higher when compared with Rice Mill Waste Biochar (RMW) and the control. MFB was statistically at bar with other biochars except for those two mentioned above.

DISCUSSIONS

The data from the result has shown that biochar can improve the soil properties, this is in agreement with the findings of Chan *et al.*, (2007) and Nelissen *et al.,* (2014) who also observed in their works on agronomic values of green waste biochar as a soil amendment and short-term effect of feedstock and pyrolysis temperature on biochar characteristics, soil and crop response in temperate soils, that applied biochar increased most of the soil properties tested. One of the evidence of these increase in soil properties is seen in the increase recorded for the soil pH from what it was before treatment application 4.8 (Table 1) to the highest value of 6.8. Researcher such as Chan *et al.,* (2008), Laird *et al.,* (2010), Van Zwieten *et al.*, (2010) observed similar increase in the pH of acidic soil when biochar was applied to the soil. Soil reac-

Table 3: Effect of treatments on soil acidity indices

Treatment	pH (H_2O)	Ex. Acidity (cmolkg-^{1})	Ex. Calcium (cmolkg^{-1})	% Al Saturation	% Ca Saturation
Control	4.5	2.18	1.66	30.16	28.91
BN	6.1	0.59	5.65	2.85	55.50
CD	6.5	1.01	5.28	4.64	49.03
MFB	6.8	0.56	6.10	2.25	52.81
CP	6.4	0.81	5.50	2.89	51.33
GD	6.6	0.77	5.20	3.52	50.00
PB	6.0	0.94	5.40	4.13	50.80
PS	6.4	0.50	5.82	2.32	54.10
PT	6.7	0.62	5.48	2.03	50.65
RMW	6.0	0.82	4.40	3.66	50.34
SD	5.9	0.90	5.23	3.80	50.00
UKP	6.6	0.65	5.33	2.32	41.93
WS	6.1	0.61	5.35	2.03	51.74
LSD $_{(0.05)}$	0.2	0.07	0.38	1.98	5.05

tion is an important factor in controlling nutrient availability and processes that take place in the soil. The pH of the soil that received the biochar produced from different sources ranged from 5.9- 6.8. These ranges according to Chude *et al.*, (2012) are rated moderately acidic to neutral. When the pH is increased from acidity to neutral, most soil essential macro nutrient such as nitrogen, phosphorus, potassium among others become available. For instance when the pH is increased to 6 -7, phosphorus becomes available and soluble (Biswas and Mukherjee, 2008) as aluminum will be precipitated from the insoluble Aluminum-phosphorus compound (Al-P) formed in acidic condition (Caires *et al.*, 2005). The result obtained showed that the pots that had increased pH values had a decreased exchangeable acidity values. Similar result of higher pH and a corresponded reduction in exchangeable acidity was reported by Onwuka *et al.*, (2011). They reported in their correlation study between soil acidity indices, exchangeable calcium and base saturation percentage that pH correlated negatively with soil acidity indices especially exchangeable aluminum which is one of the major constituent of soil exchangeable acidity and percentage aluminum saturation. While on the other hand, it correlated positively with exchangeable calcium, percentage calcium saturation and calcium aluminum ratio. The above statement may help to explain the reason why the biochars that had increased pH values such as BN, MFB, WS, PS had higher, exchangeable calcium, percentage calcium saturation and lower exchangeable acidity and percentage aluminum saturation.

It was observed that though there were significant differences in the amount of Nitrogen from

Table 4: Effect of treatments on soil nitrogen, organic carbon and available phosphorus

Treatment	N%	OC%	Av. P (mg kg^{-1})
Control	0.04	0.41	13.5
BN	0.09	1.07	60.9
CD	0.11	1.24	47.8
MFB	0.13	1.55	65.9
CP	0.11	1.25	45.7
GD	0.11	1.29	53.8
PB	0.11	1.30	44.4
PS	0.11	1.30	46.0
PT	0.12	1.39	57.6
RMW	0.09	1.09	61.4
SD	0.10	1.12	45.1
UKP	0.15	1.42	51.6
WS	0.10	1.13	41.2
LSD (0.05)	0.01	0.10	3.10

each of the biochar applied, the values were relatively low. The explanation to this may be that nitrogen was volatilized in the course of producing the biochar. The other reasons according to Nelissen *et al.,* (2014) could be due to biotic N immobilization, reduced soil organic matter (SOM) mineralization, suppressed nitrification, increased gaseous losses or abiotic NH_4^+ and/or NO_3^- immobilization. The increase in soil organic carbon observed in the pots that received biochar could be because of the organic carbon content of the biochar as shown on Table 2.

The increased soil exchangeable calcium, potassium and magnesium could be as result of the pyrolysis process which may have increased their concentration and also due to increase in pH which makes the cations available. Similar increase in potassium, magnesium, and calcium of acid soils were observed by Jin-Hua and Ren-Kou (2012) from their work on effects of biochars generated from crop residues on chemical properties of acid soils from tropical and subtropical China.

CONCLUSION

A pot experiment was conducted to characterize biochar produced from different feedstock at the same temperature and to ascertain their effect on the soil chemical properties when used as an amendment on acidic ultisol. The various biochar produced had different chemical compositions but among them, Mixed Feedstock Bi-

Table 5: Effect of treatments on soil potassium, magnesium, sodium and percentage base saturation

Treatment	K	Mg	Na	%BS
	---------------------------→	cmol kg^{-1}	←---------------	
Control	0.08	1.70	0.12	67.17
BN	0.15	3.65	0.25	94.25
CD	0.19	4.10	0.25	90.60
MFB	0.31	4.20	0.33	95.13
CP	0.10	4.00	0.20	92.43
GD	0.19	4.20	0.25	92.97
PB	0.19	4.10	0.23	91.23
PS	0.17	4.10	0.24	95.33
PT	0.21	4.10	0.24	94.27
RMW	0.11	3.20	0.23	92.54
SD	0.15	4.03	0.25	91.48
UKP	0.11	4.50	0.24	93.92
WS	0.16	3.93	0.22	94.12
LSD $_{(0.05)}$	0.06	0.34	NS	0.91

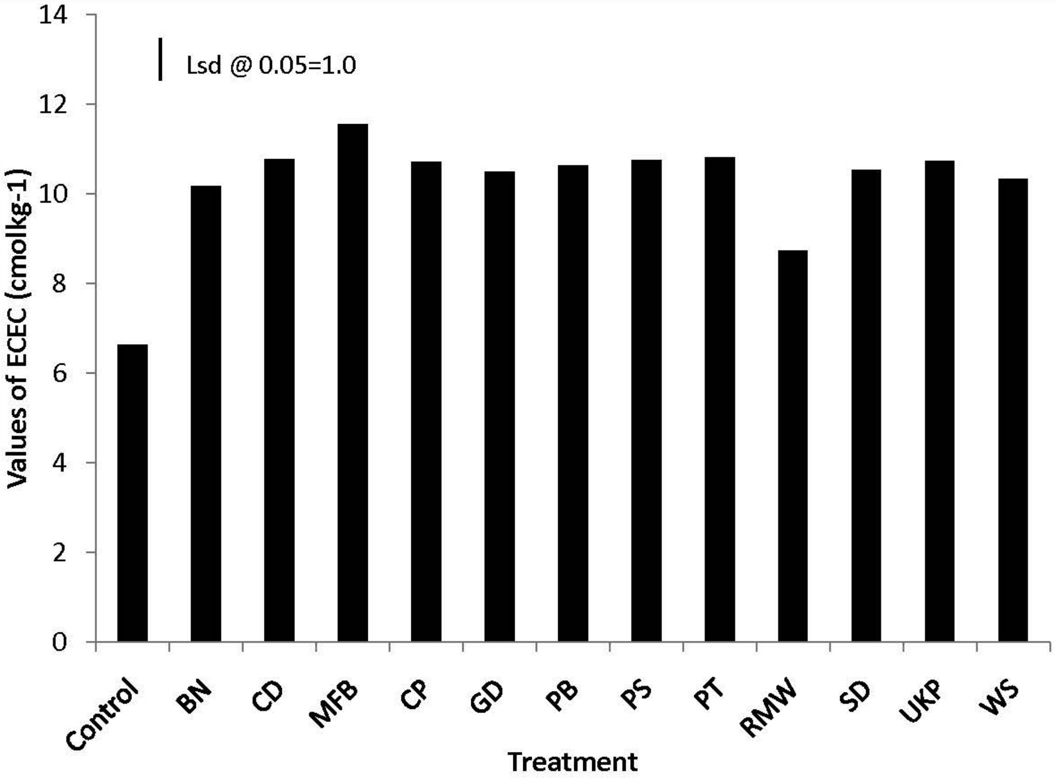

Fig 1: Effect of types of biochar on Effective Cation Exchange Capacity

ochar (MFB) showed superior nutrient content in the amount of its nitrogen, organic carbon, phosphorus and potassium. The soil used for the experiment was acidic and low in most of the nutrients tested and application of biochar improved some of the chemical properties. MFB showed an overall best performance in the parameters tested and hence, it will be appropriate to apply it to soil with decline fertility such as the one used for the study. One of the pronounced observations made was the low nitrogen content of the soil after the biochar application. This call for investigation, hence further work to determine the time of application of biochar that will allow mineralization processes to take place in soil is necessary to be conducted. Field trial of this experiment is recommended.

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