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Effects of Biochar on the Physical and Chemical Properties of Soil in Owerri, Southeastern Nigeria

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Abstract
The research was conducted to study the effects of biochar on soil physical and chemical properties in soils of Owerri, South Eastern, Nigeria. The experiment was carried out at the Department of Agricultural Science, Alvan Ikoku Federal University of Education Owerri greenhouse.0g/kg, 30g/kg, and 50g/kg of the various biochar sources namely Poultry Droppings (PD), Cow Dung (CD) and Wood Charcoal (WC) were respectively mixed with 1kg of soil sample which is equivalent to 0.000000025ha and replicated three times. The experimental design is a Factorial Arranged in a Completely Randomized Design (CRD) with the various sources of biochar as the main treatments while the various rates (0, 30g/kg, and 50g/kg) application constitutes the subplot treatments making a total of 27 experimental units. The experiment was allowed for 30 days, and adequate moisture was ensured. The data generated was subjected to analysis of variance. Results showed that the application of biochars (PD, CD and WC) to the soil studied, significantly at a 5% level of probability improved the soil physicochemical properties except for the texture of the soil. The levels of improvement increased as the rate of applications of biochar increased. The level of improvement followed the trends of $PD_{50} \geq CD_{50} \geq WC_{50} \geq PD_{50} \geq CD_{30} \geq WC_{30} \geq$ 0g/kg(control). Based on the study, therefore, biochar application is recommended to farmers because of its significant improvement in soil physical and chemical properties.

Keywords: Biochar, Soil, Physical Properties, Chemical Properties, Rainforest

Introduction

Soils in the tropical rainforest of Nigeria are inherently low in fertility and characteristically low in organic matter content and cannot sustainably support intensive cultivation due to heavy precipitation (rainfall) which causes erosion and leaching of soil nutrients. Tremendous efforts have been made by scientists to improve and boost soil fertility for sustainable crop production in soils of low inherent fertility (Udoh et al., 2016). Recently, the efforts of agricultural and environmental researchers is pointing in the direction of biochar as a variable technology that could be used to deal with some of these concerns (Ibiremo & Akanbi, 2015; Adeyemi & Idowu, 2017). Biochar is a carbon-rich and porous material that is resistant to decomposition in the natural environment due to its condensed structure (Spokas et al., 2012). Because of its stable organic carbon content, large specific surface area and negative surface.

Charges (Mukherjee et al., 2011), biochar has been widely recognized as a beneficial soil amendment for its role in improving physical (Lehmann, 2007), Chemical (Glaser et al., 2001) and biological properties (Glaser et al., 2002; Warnock et al., 2007). Biochar's ability to impact important properties of soils such as raising the soil pH and water holding capacity, attraction of beneficial microbes (bacteria, fungi etc), improvement of cation exchange capacity (CEC), high carbon sequestration ability and nutrient retention capacity as well as its large surface area makes it a potential remedy to tackle soil infertility problems. This addition of biochar to agricultural soils has been projected as a means to improve soil fertility and mitigate climate change (Aydin et al., 2008; Amutio et al., 2013). Biochar has the potential to reduce nutrient leaching, thereby improving crop production in coarse-textured soil (Verheijen et al., 2010; Uzoma et al., 2011). Soil nitrogen (N) mineralization rates have been formed to be affected by biochar amendments particularly manure-based biochars, which can be a source of N for plants (Gaskin et al., 2008). Compared to other soil amendments, the high surface area and porosity of biochar enable it to absorb or retain nutrients and water and also provide a habitat for beneficial microbes to flourish (Gaskin et al., 2008).

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Moreover, biochar is considered to be relatively stable in soil with mineralization rates that are slower than that found in the original biomass. Additionally, the porous structure of biochar that retained water and improved water balance resulted in better nutrient availability. Also, biochar amendments increased the soil organic carbon (SOC) and total nitrogen (Zhang, et al., 2010; Beck et al., 2011). This study was therefore undertaken to assess the effects of biochar on soil physical and chemical properties in soils of Owerri, South Eastern Nigeria.

Materials and Methods

Description of the Study Area

A pot trial was conducted in a greenhouse of the Department of Agricultural Science Teaching and Research Farm, Alvan Ikoku Federal University of Education Owerri. The area is characterized by a tropical climate which is controlled by high rainfall. It has a mean annual rainfall of 2360 mm with a bimodal distribution pattern. Ambient temperature and relative humidity are high throughout the year. The mean minimum temperature varies between 21°C and 30°C. The mean relative humidity varies between 60 to 90% (Simon, 2010).

Preparation of Research Materials

Twenty-seven (27) plastic buckets of 4 litres capacity were perforated at the bottom to allow for easy drainage of water. Biochar made from poultry droppings (PD), Cow dung (CD) and Wood charcoal (WC) was mulled using a mechanical blender and sieve with a 4mm size plastic sieve to obtain its smooth fine powder. Topsoil was taken at a depth of 0-20 cm from the Teaching and Research farm, Department of Agricultural Science, Alvan Ikoku Federal University of Education Owerri with the help of a spade. Soil Samples were air-dried and sieved using 4 mm size plastic sieve. One (1) kilogram of sieved soil was weighed to all the twenty-seven (27) plastic buckets and placed in the greenhouse.

Experimental Design and Treatments

The experimental design is a Factorial Arranged in a Completely Randomized Design (CRD) with the various sources of biochar, poultry droppings (PD), cow dung (CD) and Wood charcoal (WC) as the main treatments while the different rates/levels (0g/kg, 30g/kg and 50g/kg) application constitutes the subplot treatments giving a total of 27 samples. The experiment was allowed for 30 days, and adequate moisture was ensured.

Laboratory Analysis

Samples of biochar and soil were subjected to chemical analysis using standard procedures as outlined by Udo et al. (2009). Particle size distribution was determined by the Bouyancy hydrometer Method. Soil pH was determined in 1:2.5 soil, water ratio with pH meter. Organic carbon was determined by Walkley Black Dichromate Oxidation Method. The Nitrogen (N) was determined by the Micro kjeldahl Method. Available phosphorus (P) was extracted by the Bray-11 extraction Method, and the content of P was determined colorimetrically using a Technico AA11 auto analyser (Technico, Oakland, Calif). Exchangeable bases (K, Na, Ca, and Mg) were extracted with 0.1N ammonium acetate; K and Na were extracted with a flame photometer while Ca and Mg were determined through EDTA titration Method. Exchangeable acidity was determined by leaching the soils with 0.01 NaOH. Effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable bases (Ca, Mg, Na and K) and exchangeable acidity (H and Al). Base saturation was calculated by dividing the sum of exchangeable bases by ECEC and multiplying by 100.

Preparation of Biochar

Biochar was prepared from poultry droppings (PD), cow dung (CD), and wood charcoal (WC), they were air-dried at room temperature and ground to pass a 4mm sieve and used to tightly fill ceramic crucibles, each covered with a fitting lid. Then the materials with the ceramic crucible were placed in a muffler furnace to pyrolyze under oxygen-limited conditions. The pyrolysis temperature was raised to 35°C at a rate of approximately 20°C min-1 and kept constant for 4 hours and then biochar was allowed to cool to room temperature inside the muffled furnace (Yuan & Xu, 2012). The data generated were subjected to analysis of variance.

Results and Discussion

Table 1 displays the physicochemical properties of the soil before the experiment. It was observed that the soil belong to the loamy sand texture with the values of 972.40gkg^{-1}, 54.00gkg^{-1} and 153.60gkg^{-1} for sand, silt and clay respectively. The soil had low moisture content (8.5%), bulk density (1.33gcm^{-1}) and porosity (48%). The soil was acidic in both water (5.68) and KCl (5.54). The acidic nature of the soil was usual for ultisols (Lal, 1987) due to high precipitation. Organic carbon (8.36gkg^{-1}) and organic matter (14.41gkg^{-1}) were low compared

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to the standard 4-10gkg^{-1} and 20-40gkg^{-1} for organic carbon and organic matter respectively according to the rating of FAO (2004). Nitrogen and phosphorous were also low with values of 0.89gkg-1 and 3_c63gkg^{-1} respectively. The soil had low exchangeable Ca (1.48 cmol/kg) Mg (1.06 cmol/Kg), K(0.123 cmol/kg) and Na (0.054 cmol/kg). The total exchangeable acidity recorded in the soil may be a result of low pH and corresponding low total exchangeable bases of the soil. The moderate total acidity of the soil perhaps may be the reason for high percentage base saturation (% Bs) (69.0%)

Table 1: Showing soil physical and chemical properties of the soil before the experiment

Parameters	Values
Sand (gkg^{-1})	792.40
Silt (gkg^{-1})	54.00
Clay (gkg^{-1})	153.60
Textural Class	Loamy sand
Moisture (%)	8.5
Bulk density (gcm^{-3})	1.33
Porosity (%)	48.0
pH in H_20	5.68
pH in KCl	5.54
Organic Carbon (gkg^{-1})	8.36
Organic matter (gkg^{-1})	14.41
Total N (gkg^{-1})	0.89
Exchangeable P (gkg^{-1})	3.63
Cations (cmol/kg)	
Ca	1.48
Mg	1.06
K	0.123
Na	0.054
TEA ($AI^{3+}H^{+}$)	1023
TEB (Ca + Ng + Na + K)	2.717
ECEC (TEA + TEB)	3.947
BS (%)	69.00
Cu (mgkg^{-1})	10.50
P6 (mgkg^{-1})	0.68

Physico Chemical Properties of Biochar Used

Biochar as a potential absorbent material is a product of the decomposition of organic material under the limited supply of oxygen at temperatures between 350°C and 700°C (Glases, et al, 2001). Cellulose-rich biomass water from agriculture and forestry (such as plant residues, wood waste, peat, cattle manure, poultry manure and others is used as feedback (FAO, 2004). Biochar therefore are organic materials and organic amendments that can render heavy metals immobile and bioavailable by various physico-chemical means (Bolan & Duraisamy 2003). Table 2 depicts selected physico-chemical properties. The biochars were alkaline having pH of 9.3, 7.3 and 8.3 for Cow dung, Wood charcoal and Poultry dropping respectively.

Organic carbon of the biochars from animal sources i.e. Cow dung and Poultry droppings are far higher over 231 and 354gkg^{-1} respectively compared to wood charcoal (30gkg^{-1}). In general, the carbon content of biochar is inversely related to biochar yield. This result was in disagreement with the findings of Lehmann et.al, (2003) who reported that biochars tend to have a high C content when poultry dropping (20.2gkg^{-1}) highest compared to Cow dung (18.05gkg^{-1}) and wood charcoal (10gkg') biochars. Despite seemingly high, biochar total N content may not be necessarily beneficial to crops, since N is mostly present in an unavailable form (Mineral N content <2mgkg^{-1}) (Chan and Xu, 2009).

Similarly, C/N ratio of poultry dropping was high (17.48) compared to cow dung (12.8) and wood charcoal (8.0) biochars. The high C/N ratios of most biochars such as witnessed in poultry droppings suggest that N will be immobilized but doubt exists about whether this line of reasoning applies directly to biochar is resistant to microbial decay, it has been suggested that immobilization is negligible (Lehmann et.al, 2003). The Ash content of cow dung biochar (7545gkg^{-1}) was higher than 625gkg^{-1} and 280gkg^{-1} recorded for poultry dropping and

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wood charcoal biochars. The ash content of the biochar is dependent on the ash content of the biomass feedstock, Grass, grain, husks, straw residue and manures generally produce biochar with high ash contents in contrast to that from woody feedstocks (Bolan and Duraisamy, 2003). According to Kim et al. (2009) concentrations of ash in biochar range from less than 1% in softwood to sometimes greater than 60% in animal manure biochar.

Moisture is another critical component of biochar according to Antal and Gronlic (2003) moisture content of the biochar from animal feedstocks, cow dung (13.9gkg^{-1}) and poultry (16-5 gkg^{-1}) biochar was higher compared to 6.7gkg^{-1} recorded in wood charcoal biochar. According to Gaskin et.al. (2008) and Novak et al. (2009) CEC in biochar is dependent on the levels of minerals in the feedstock and pyrolysis temperature at production, this perhaps may explain the reason for higher (CEC) recorded in poultry dropping biochar on the other hand, biochars have heavy metal inherent within their structures derived from their source materials which may be accumulated and concentrate in ash fraction during pyrolysis. The highest (0.30gkg^{-1}and 0.65gkg^{-1}) lead and copper were recorded in poultry droppings and cow dung biochar respectively. However heavy metal concentrations in the biochars were very low compared to those in the soil and hence the amount of each metal added to the soil through biochar application was negligible.

Table 2: Physicochemical Properties of Biochar

Parameters	Units	CD	WC	PD
pH	(gkg^{-1})	9.3	7.3	8.3
Total N	(gkg^{-1})	18.05	10	20.25
C:N ratio		12.8	8	17.48
Ash content	(gkg^{-1})	745	280	625
Moisture content	(gkg^{-1})	13.9	6.7	16.5
Total P	(gkg^{-1})	42.5	28.2	57.2
Na+	(mgkg^{-1}) cmol/kg	0.77	0.3	1.25
Ca++	(mgkg^{-1}) cmol/kg	4.72	1.65	6.27
Mg++	(mgkg^{-1}) cmol/kg	1.25	0.14	2.77
K+	(mgkg^{-1}) cmol/kg	2.5	0.99	3.75
EA(Al + H)	(mgkg^{-1})	4.25	0.32	5.25
CEC	(cmol/kg^{-1})	13.49	4.33	19.29
Pb	(mgkg^{-1})	0.25	0.21	0.30
Cu	(mgkg^{-1})	0.51	0.45	0.65

Where CD = Cow Dung
WC = Wood Charcoal
PD = Poultry Droppings

Impact of Biochar on the Chemical and Physical Properties of Soil.

From this result, it shows that there is great improvement on the soils amended with biochar and the rate of improvement increases as the rate of the applications increases. The result of the effect of biochar on soil physicochemical properties was shown in Table 3.

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Table 3: Effects of biochar on soil physical and chemical properties

Treatment	Sand glkg	Salt glkg	Clay glkg	Texture class	Moisture intent (%)	Bulk Density (g/cm³)	pH in H_2	pH in KCC	Organic Carbon (g/kg)	Organic Matter g/kg	TN (glkg)	Exchangeable p (glkg)	TEB	BS(%)	ECEC
Control	792.00	54.00	15760	LS	8.5	1.37	4.79	4.42	1.02	1.78	0.89	3.63	2.72	63.70	4.27
PD_{50}	790.00	60.00	150.00	LS	10.73	1.22	5.9	5.62	1.72	2.97	1.25	4.20	3.28	65.70	5.01
PD_{50}	750.00	72.00	178.00	LS	12.50	1.19	6.2	5.95	1.94	3.34	1.57	6.20	4.05	69.35	5.84
CD_{30}	780.20	65.10	154.70	LS	10.50	1.26	5.5	5.42	1.70	2.93	1.15	3.70	3.35	67.35	4.98
CD_{50}	785.00	60.50	154.50	LS	11.90	1.23	6.0	5.85	1.82	3.14	1.27	5.20	4.04	77.84	5.19
WC_{30}	800.00	65.00	135.00	LS	9.10	1.27	5.6	5.47	1.65	2.84	1.12	4.05	2.95	64.27	4.59
WC_{50}	790.50	57.50	152.00	LS	10.10	1.25	5.9	5.72	1.77	3.05	1.20	4.80	3.34	66.67	5.01
LSD_{005}	NS	NS	NS		1,27	1.05	1.07	1.02	0.82	0.65	0.02	0.07	1.07	1.25	0.84

KEY
LS = Loamy Sand
KCl = Potassium chloride
TN = Total Nitrogen
Exchangeable P = Exchangeable phosphorus
Cu^{2+} = Copper
Mg^{2+} = Magnesium
K^+ = Potassium
TEB = Total exchangeable bases (cmol/kg)
BS = Base saturation
ECEC = Effective cation exchange capacity (cmol/kg).

The sand fractions dominate other fractions in the study, this can be attributed to the sandy. (Coastal Plain Sand) nature of soils of South Eastern Nigeria occasioned by high precipitation (rainfall).

The texture generally is loamy sand in all the soil samples tested. The biochar, however, does not significantly influence the probability level of 5%.

Moisture Content: It significantly influences the moisture content at a probability level of 5%.
Poultry dropping at 50gkg^{-1} recorded the highest improvement12.50 (10.759) and was seconded by cow dung at 50gkg^{-1} (11.90%) and thirdly wood charcoal at 50gkg^{-1} recorded at the rate of (10.10%) respectively compared to the control (8.5%).
Poultry dropping at 30gkg^{-1} was recorded (8.5) and was seconded by cow dung at 30gkg^{-1} (10.50%) and thirdly wood charcoal at 30gkg^{-1} (9.10%) respectively.

Bulk Density: This shows that there is a great improvement in poultry dropping at the rate of 50gkg^{-1} (1.19gcm^{-1}) relative to the control that recorded 1.37gcm^{-3}. The rate of improvement of biochar increases on bulk density as the rate increases in all the organic amendments studied. This is agreed by the work done by (Jiang et al., 2012) that the addition of biochar to the soil improves soil bulk density, infiltration rate, moisture content etc. The biochar significantly influences the bulk density at a probability level of 5%.

Organic Matter

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This shows that there is a great improvement in Poultry dropping biochar at the rate of 50gkg^{-1} (3.34gkg^{-1}) relative to the control that recorded 1.78gkg^{-1} which was seconded by cow dung at the rate of 50gkg^{-1} (3.14gkg^{-1}) relative to the control that recorded 1.78gkg^{-1} and followed by wood charcoal at the rate of 50gkg^{-1} (3.05gkg^{-1}) relative to the control at 1.78gkg^{-1}The rate of improvement of biochar on organic matter increases in all the amendments studied, this agreed by the work done by Uchimiya at al. (2011) that biochar, however, can be used as organic amendments to immobilize heavy metals in acid soils and to reduce the availability and phytotoxicity to plants. The biochar significantly influenced the organic matter with a probability of 5%.

Total Nitrogen

This shows that there is a great improvement in poultry dropping biochar at the rate of 50gkg^{-1} (1.57%) relative to the control that recorded 0.89%which was followed by cow dung (1.27%) at the rate of 50gkg^{-1} relative to the control that recorded 0.89% and was followed by wood charcoal at the rate of 50gkg^{-1} (1.20%) relative to the control that recorded 0.89% this shows that the rate of improvement in the application of biochar on total nitrogen increases as the rate of application increases, this is agreed by the work done by Sohi et.al. (2010). However, depending on the sources, biochar may supply certain amounts of phosphorus and potassium to crops but will supply little nitrogen, on the other hand, biochar promotes the growth of beneficial microbes and helps retain nitrogen, phosphorus, and potassium to crops in the soil thereby improving the crop utilization efficiency of the nutrients. The biochar significantly influences total nitrogen on the probability of 5%.

Exchangeable Phosphorus

The rate of improvement of biochar on exchangeable phosphorus in poultry droppings at the rate of 50gkg was recorded at 6.20gkg^{-1} and was seconded by cow dung at the rate of 50gkg^{-1}which also recorded 5.20gkg^{-1} and finally wood charcoal at the rate of 50gkg relative to control at 4.80% this shows that the rate of improvement due to the application of biochar on exchangeable phosphorus increases as the rate of application increases. The biochar significantly influenced exchangeable phosphorus on the probability of 5%. This is agreed with the work done by Sohi et al. (2010) the amount of biochar that can be added to soils before it ceases to function as a beneficial soil amendment and becomes detrimental will be the limiting factor in the use of biochar as an addictive.

Total Exchangeable Bases

This shows that there is improvement in poultry droppings at the rate of 50gkg^{-1} 4.05cmolkg^{-1} relative to the control that recorded 2.72cmolkg^{-1}and was seconded by cow dung at the rate of 50gkg^{-1} which recorded 4.04% and was followed wood charcoal at rate of 50gkg^{-1} 3.34cmolkg^{-1} respectively. The rate of biochar application increases on total exchangeable bases and this agrees with the work done by Lehmann et al. (2003). Biochar is generally used as a soil amendment and in soil treatments. The biochar significantly influenced the total exchangeable bases at the probability of 5%.

Base Saturation

This shows that there is improvement in base saturation on poultry dropping at a rate of 50gkg^{-1} (69.35%) relative to control at 63.70%and seconded by cow dung 50gkg^{-1} (77.84%) relative to control (63.70%) and was followed wood charcoal at 50gkg^{-1} (66.67%) relative to control 63.70% respectively. This study shows that the impact of biochar on soil increases at the rate of applications increases and this agrees by the work done by Novak et.al, (2009) biochar and bio-energy co-production from urban agricultural forestry biomass can help combat global climate change by a number of different pathways. The biochar significantly influenced base saturation at the probability of 5%.

Effective Cation Exchange Capacity

This shows that there is improvement in ECEC on poultry droppings at the rate of S0gkg^{-1} (5.8cmolkg^{-1}) relative to control at (4.27cmolkg^{-1})and was seconded by cow dung at the rate of 50gkg^{-1} (5.1cmolkg^{-1}) in relative to control at (4.27cmolkg^{-1}) and finally wood charcoal at the rate of 50gkg^{-1} (5.0cmolkg^{-1}) relative to control at (4.27cmolkg^{-1})This study show that there is improvement on ECEC of the soil and this agrees by the work done by Jiang et.al, (2012) that addition of biochar improves soil bulk density, infiltration, moisture content and CEC. The biochar significantly influenced ECEC at the probability level of 5%.

Conclusion

The application of biochar (PD, CD and WC) significantly at *a 5%* level of probability improves the soil's physical and chemical properties. The application of biochars (PD, CD and WC) does not significantly influence the texture of the soil studied. The level of improvement in the soil physicochemical properties increased as the

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rate of application increased. The highest improvement was observed in poultry dropping at $50gkg^{-1}$ followed by cow dung at the same rate. The trends of improvement of biochar (PD, CD, WC) followed the order $PD_{50} \geq CD_{50} \geq WC_{50} \geq PD_{30} \geq CD_{30} \geq WC_{30} \geq$ control.

Recommendations

1. Farmers should be encouraged to use biochar as a source of soil amendments because of its enormous influence on soil physical and chemical properties.
2. Application of $50gkg^{-1}$ of biochar, (poultry droppings, cow dung and wood charcoal) should be encouraged because of easy and timely release of plant nutrients.
3. Further study should be geared toward determining the effects of these biochars on crop growth and yield.

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