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IMPACT OF BIOCHAR FROM DIFFERENT AGRICULTURAL WASTES ON SOIL CHEMICAL CHARACTERISTICS AND GROWTH OF MAIZE

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ABSTRACT

The use of biochar as soil amendment is gaining acceptance as an important management strategy to tackle food insecurity for the growing population in Nigeria amid soil deterioration. This study examined the influence of biochar produced from the different agricultural wastes on soil chemical characteristics and growth of maize. A pot experiment was conducted at the greenhouse of Imo State University Owerri, Nigeria. The experiment was laid out in completely randomized design. The agricultural wastes used were rice husk, corn cob, poultry manure and pig dung. The agricultural wastes were charred differently for 60 minutes at the temperature of 250^{o}C. The maize plant used for the experiment was Oba super II. The biochar was produced using modified biochar kiln and were applied to the soil at the rate of 10t ha^{-1}. The treatments were replicated thrice. Soil amended with poultry manure charred for 60 minutes at 250^{o}C (PMB60) had the highest significant growth (plant height) and yield (dry matter) parameters. Significant differences were observed among the biochar amendments with the soil chemical characteristics (pH, Available P, SOM, TN, Exchangeable base cations and CEC). However, the study reported that PMB60 gave the highest significant increase in almost all the soil chemical characteristics (soil pH(6.0), Avail. P(18.20mg kg^{-1}), exchangeable Ca(5.8Cmol kg^{-1}), Mg(3.97Cmol kg^{-1}, K(0.32Cmol kg^{-1}, Na(0.28Cmol kg^{-1}) and CEC(10.75Cmol kg^{-1})) compared to the other biochar amendments. This study concluded that PMB60 was better suited to improve soil chemical characteristics while also improving maize performance compared to the other biochar amendments.

Keywords: Biochar, Agricultural waste, Soil chemical properties, Maize
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INTRODUCTION

Biochar is a carbon-dense substance produced through the pyrolysis of biomass either from agricultural waste or municipal waste with limited or no oxygen (Lehmann & Joseph, 2009). The use of biochar as amendment materials in agricultural soils is receiving much attention due to the obvious benefits of biochar. Research has shown that the benefits of biochar include enhancement of soil fertility, long term soil carbon sequestration, decrease in greenhouse gas

(GHG) emissions, and decrease in loss of nutrients through leaching (Lahmann, et al., 2006). Biochar serves as a P, K, and other nutrients source though it contributes little (Glaser et al., 2002). According to Chan et al. (2008), biochar is known to raise soil pH and in so doing improve the availability of nutrients to crop plants. This is because soil pH is an important factor in determining the bioavailability of nutrients in the soil. According to Lin et al. (2018), application of peanut shell biochar on strongly acidic red soil was found to enhance cabbage growth by mitigating Al toxicity through elevated soil pH and increased nutrient availability. Biochar application had a positive impact on moisture holding capacity and soil structure (Wardle et al., 1998). Microbial population enhancement had also been reported with biochar application (Basso et al., 2013). Soil infertility is a very strong challenge that prevents crop from attaining higher potential yields especially essential cereal crop like maize which is a crop that has undergone thorough and robust growth (Ahmed, 1996).

Maize (Zea mays) is one of the crops with the highest nutrient demand in the world (ThriveAgric, 2020). This is because of its extensive uses which include acting as a primary source of calories in animal feed formulation. According to World Corn Production (2022/2023), the global production of maize in the world in 2022 was about 1,216.87 million tonnes. In that same year, Africa had a total production volume of about 90 million metric tonnes and Nigeria production volume of about 12 million metric tonnes. Despite the importance of maize to the teeming population of Nigeria, its production and consumption data have pinpointed a deficit of over 8.0 million metric tonnes which have hiked the price of maize (Ibirogba, 2022). Ecologically, Nigeria has comparative advantages over other Africa countries but still experiencing low production in maize. This could be attributed to soil deterioration being experience in many Nigeria soils. Intensive cultivation of soil with high levels of chemical fertilizers, leads to quick decomposition of organic matter into carbon dioxide through the activities of soil microorganisms. This will increase the released of gas into the atmosphere, leaving the soil compacted and poor in nutrient as well as adding to global warming (Ndor et al., 2010). One feasible measure to increase soil fertility for agricultural sustainability is through the addition of biochar as soil amendment (Verheijen et al.,2010).

However, very few studies have specifically focused on the impact of biochar produced from different agricultural wastes on soil with low nutrient content. Therefore, the objective of this research is to assess the impact of biochar produced from different agricultural wastes on soil chemical characteristics and growth of maize.

Materials and Methods

Soil and Biochar Preparation

The soil used for the experiment was collected from the research field of Faculty of Agriculture Teaching and Research Farm, Imo State University, Owerri Nigeria at the depth of 0 – 15 cm. The collected soil was air dried, crushed, passed through 2mm sieve and 2 kg was filled into each plastic pots. The initial properties of the soil used are shown in Table 1. The agricultural wastes used for this experiment include rice husk, corn cob, poultry manure and pig dung which were sourced locally from commercial farmers. The rice husk and the corn cob were first air-dried and grounded using a modified hand blender powered by petrol engine before pyrolysis. The poultry manure and pig dung were only air-dried before pyrolysis. Prior to the insertion of the feedstocks, the biochar machine was first heated for 10 minutes. One kg of each agricultural waste residue was inserted into the modified gas biochar kiln and charred at 250 ^{o}C for 60 minutes. The produced biochar was analyzed for its chemical composition before its application to the soil (Table 2).

Pot Experiment

A pot experiment was conducted in a greenhouse at the Faculty of Agriculture Teaching and Research Farm, Imo State University, Owerri Nigeria (05°30' N and 07°2' E) from February to May 2022. The size of the plastic pots used for the experiment was 18 cm in diameter and 17 cm in height. The pots were filled with 2 kg of soil and amended with 10 g pot^{-1} each of the different biochar (at the rate of 10t ha^{-1}). The pots were laid out in a completely randomized design (CRD) and replicated thrice. All the experimental pots were irrigated 5 cm above the soil level prior to planting. Maize seed (Oba super II) was planted in the pots after 24 hours of irrigation. The average temperature during the experiment was 27^{o}C with minimum of 23^{o}C and maximum of 32^{o}C while the relative humidity was in the range of 63 – 80 % during the experimental period.

Crop Parameters

The maize plant height, number of leaves and leaf area were measured at 6 weeks after germination. The maize plants were harvested after the measurements were taken washed with running water and air dried for two days in the greenhouse. The harvested and air dried maize plants were folded and inserted into a paper bag and further oven dried at 60^{o}C until a constant weight was achieved. The soil from each pot was air-dried, homogenized and passed through a 2 mm sieve to remove any visible roots in the soil and used for soil chemical analysis.

Analyses of Chemical characteristics for Soil and Biochar

Soil pH was estimated using 1:2.5 soil–water ratio using a pH meter (Thomas, 1996). Available phosphorus was determined using Bray 2 method (Olsen & Sommers, 1982). Total nitrogen was determined by Micro-kjeldahl digestion technique (Bremner, 1996). Organic carbon was determined by wet digestion method (Nelson & Sommers 1982). Exchangeable bases and CEC were determined by neutral ammonium acetate procedure buffered at pH 7.0 (Thomas, 1982).

The pH of the biochar was measured in 1:20 w/v biochar water extracts using pH meter. The different feedstock biochars were each digested by nitric and perchloric acid (Kalra et al., 1988) and then the extract were used to measure total elements (P, Ca, Mg, Na and K) according to the standard methods. Phosphorous content from the biochar extractant was determined calorimetrically using spectrophotometer. Organic Carbon was determined using Walkley and

Black dichromate method (Nelson & Sommer, 1982). Nitrogen was estimated using macro - kjeldahl method (Bremner & Mulvaney, 1982).

Data Analysis

Analysis of Variance (ANOVA) was used to verify the statistical difference between the different biochar amendments using SPSS version 25. The means were compared using Duncan's multiple range tests at $P < 0.05$.

RESULTS AND DISCUSSION

Soil Initial Characteristics before the Greenhouse Experiment

The physical and the chemical characteristics of the soil used for the greenhouse study are shown in Table 1. The soil was of loamy sand texture (sand 812g kg^{-1}, clay 124g kg^{-1} and silt 64g kg^{-1}). The soil pH is moderately acidic while available P and total nitrogen were low with medium organic matter content according to the rating of Esu (1991). The CEC of the used soil was medium in rating. The values of exchangeable bases (Ca, Mg, Na and K) of the soil used in the experiments revealed that Mg was high, Ca and Na were medium and K was low.

The Chemical Characteristics of the Biochar Used for the Greenhouse Experiment

The chemical characteristics of the four biochar produced from the four different agricultural wastes are presented in Table 2. Among the biochar produced from different feedstocks; poultry manure gave the highest pH value (9.2). This might be an attribute of biochar ash content (Gaskin et al., 2008). The biochar yield ranges from 56 – 84 % with the highest value from pig dung (84%) and the lowest from corn cob (56%). The variation found in the biochar yield is a function of type of feedstock used (Downie et al., 2009). Highest total phosphorus was found with the poultry manure (21.0 gkg^{-1}). The total N of the produced biochar ranges from 5.2 to 8.9 gkg^{-1} with the highest value from rice husk (8.9 gkg^{-1}) while the lowest was from corn cob (5.2 gkg^{-1}). The high TN found in the charred agricultural waste biochar is because once biomass is subjected to pyrolysis, some nitrogen undergo a conversion into heterocyclic N aromatic structures (Cao & Harris 2010; Koutcheiko et al., 2006). Rice husk gave the highest organic carbon after charring while poultry manure was the lowest. The value of the organic carbon obtained after charring is a function of the type of feedstock. Biochar produced from animal waste (poultry manure and pig dung) gave higher Total P, Ca, Mg, K and Na compare to the plant-based counterpart. The high values found in the total base elements after charring of the original biomass indicate that there is concentration of the relevant chemical components in biochar as heat passed through the crop residues (Yuan et al., 2011).

Impact of Biochar on Maize Plant Parameters

The results of plant height, number of leaves and dry matter yield of maize treated with different biochar are presented in Table 3. The data revealed that addition of biochar significantly ($P < 0.05$) influence the maize plant height. The highest mean value for plant height (76.67cm pot^{-1}) at six weeks after germination (WAG) was obtained from the maize treated with pig dung biochar charred at 250^{o}C for 60 minutes (PDB60), while the lowest was from control (45.33 cm pot^{-1}) which contained no biochar amendment. Number of leaves and leaf area showed no significant ($P < 0.05$) effect with biochar amendments. Dry matter data showed significant ($P < 0.05$) variation among the treatments evaluated. The highest dry matter yield (6.4g pot-1) was observed in pots treated with poultry manure charred at 250^{o}C for 60 minutes and applied at10t ha^{-1} (PMB60) (Table 3). The lowest dry matter yield (3.0g pot^{-1}) was from pots treated with rice husk charred at 250^{o}C for 60 minutes and applied at 10t ha^{-1} (RHB60). Increase seen with the addition of biochar especially in plant height and dry matter is an indication that plants nutrient uptake was increased by the addition of biochar (Atkinson et al., 2010).

Impact of Biochar on Soil Chemical Characteristics

The pHs of all biochar amended pots were higher compared to the control (the unamended pot). The pH of the pots treated with PDB60 was highest among other biochar treatments (Table 4). Biochars are predominately alkaline (pH > 7) with elevated base cations concentrations. Consequently, adding biochar to the soils can release basic cations into the soil solution, which help to reduce acidity through proton consumption reactions as indicated by Chintala et al. (2014). The increase in soil pH after amendment application could be directly linked to the higher pH of the biochar used in the study. In this study, pH increased was a function of the type of biochar used. The pH of soils treated with animal-based biochar (PMB60 and PDB60) had higher pH when compared with the plant-based (RHB60 and CCB60 (Corn cob charred at 250^{o}C for 60 minutes and applied at 10 t ha^{-1}) (Table 4). The result is in agreement with the findings of previous researchers (Mensah & Frimpong, 2018; Manolikaki & Diamadopoulos, 2019). Biochar application significantly ($P < 0.5$) increased soil organic matter (SOM). Pots treated with RHB60 gave the highest (31.0 gkg^{-1}) SOM which is statistically similar with PMB60 (Table 4). The lowest SOM was found on control (21.70 gkg^{-1}). The rise of SOM in biochar amended soil can be attributed directly to the high carbon content of the amended biochar. According to Mensah and Frimpong (2018), the application of biochar can increase carbon accumulation and sequestration. The high SOM on PMB60 might be due to remaining debris of wood shaving after sorting from the poultry manure used.

Total nitrogen (TN) in all the biochar amended pots were significantly ($P < 0.05$) higher than the control (Table 4). The TN value ranges from 0.68 g kg-1 – 1.58 g kg-1 with the highest TN value on PDB60 amended soil. In general, the biochar produced from animal sourced agricultural waste gave higher TN relative to plant based biochar (Table 4). Khan et al. (2018) found that the application of all biochar types increased soil TN relative to the control. The application of biochar significantly ($P < 0.05$) increased the soil available phosphorus contents (Table 4).The pot amended with PMB60 gave the highest soil available P content (18.20 mg kg^{-1}) while the lowest was from unamended pot (control) (12.23 mgkg-1). The increases in the soil available P observed in the biochar amended soils, could be attributed to reduced Fe and Al activity due to increase in the soil pH (5.4 – 6.2), exchangeable bases and cation exchange capacity. In a similar study, Sasmita et al. (2017) found that application of biochar with or without organic fertilizer

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led to consistent linear increase in the soil available P in Indonesia acidic soil medium during a 15-day incubation period.

Significant changes ($P < 0.05$) in soil exchangeable base (Ca, Mg, K and Na) contents and CEC as influenced by the application of biochar were presented in Table 4. The highest exchangeable Ca, Mg, K, Na and CEC (5.80 Cmol kg^{-1}, 3.97 Cmol kg^{-1}, 0.32 Cmol kg^{-1}, 0.28 Cmol kg^{-1} and 10.75 Cmol kg^{-1} respectively) were found on pots amended with PMB60. The high values seen with PMB60 may be attributed to the high content of base nutrient found in the said poultry manure biochar (Table 2). CEC represents the soil capability to retain nutrient and therefore soil with low CEC will be susceptible to nutrient leaching. Biochar been porous in nature with the higher surface area can retain more nutrients on its charge surfaces making nutrients less mobile (Jien & Wang, 2013). In general, the animal-based biochar gave a higher effect on exchangeable bases and CEC when compared with the plant-based biochar counterpart (Table 4).

CONCLUSION

The study showed that application of biochar produced from different agricultural waste significantly increased soil pH, total organic carbon, available phosphorus, total nitrogen, exchangeable base cations and cation exchange capacity in the soil. The highest effect of all the soil chemical properties evaluated were observed on PMB60 treated pots with the exception of TN (PDB60) and soil organic matter (RHB60). Additionally, the application of biochar has a significant ($P < 0.05$) effect on both plant height and dry matter yield with PMB60 standing as the best biochar treatment in maize growth and yield parameters. In conclusion, the study demonstrated that the application of PMB60 offers the best potential to enhance soil quality and improve maize yield. This been a preliminary finding, we propose a longer term study to examine the long-term effects of the treatments on soil chemical characteristics and growth of maize

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APPENDICES

Table 1: Soil Physicochemical Properties prior to greenhouse study

Soil parameters	Value
Sand (g kg-^{1})	812
Silt (g kg-^{1})	64
Clay (g kg-^{1})	124
Textural class	**Loamy sand**
Soil pH	5.4
Available Phosphorus (mg kg^{-1})	13.5
Total nitrogen (g kg^{-1})	1.02
Organic matter(g kg^{-1})	19.3
Exchangeable cations	
Calcium (Cmol kg^{-1})	3.20
Magnesium (Cmol kg^{-1})	1.20
Potassium (Cmol kg^{-1})	0.14
Sodium (Cmol kg^{-1})	0.14
Cation exchange capacity (CEC) (Cmol kg^{-1})	6.14

Table 2: Chemical characteristics of the biochar used for the greenhouse experiment

Agricultural wastes	Biochar Yield	pH (H_2O)	Total P	Total N	Organic Carbon	Total Ca	Total Mg	Total K	Total Na
	%				gkg^{-1}				
Corn cob	56.0	6.7	12.0	5.2	102.7	7.2	4.2	8.0	2.4
Rice husk	74.0	5.9	15.2	8.9	181.4	6.9	4.1	9.1	2.1
Poultry manure	67.7	9.2	21.0	8.6	95.9	8.9	5.6	12.0	2.8
Pig dung	84.0	8.4	18.0	8.1	101.0	8.4	5.2	10.6	2.9

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Table 3: Impact of Biochar on Maize Growth and Yield Parameters

Biochar Amendments	Plant Height cm pot^{-1}	Number of Leaves	Leaf Area cm^2 pot^{-1}	Dry Matter g pot^{-1}
Control	45.33^{b}	13.00^{a}	201.37^{a}	4.40^{bc}
RHB60	65.33^{a}	12.33^{a}	182.17^{a}	3.00^{c}
CCB60	59.67^{ab}	13.67^{a}	154.53^{a}	5.03^{ab}
PMB60	74.83^{a}	12.67^{a}	193.30^{a}	6.40^{a}
PDB60	76.67^{a}	11.67^{a}	215.77^{a}	3.90^{bc}

Note: Control = No biochar amendment; RHB60 = Rice husk charred at 250°C for 60 minutes and applied at $10tha^{-1}$; CCB60 = Corn cob charred at 250°C for 60 minutes and applied at $10tha^{-1}$; PMB60 = Poultry manure charred at 250°C for 60 minutes and applied at$10tha^{-1}$; PDB60 = Pig dung biochar charred at 250°C for 60 minutes and applied at $10tha^{-1}$

Table 4: Impact of biochar produced from different agricultural waste on soil chemical properties

Biochar Amendments	pH	T.N	SOM	Avail. P	Ca	Mg	K	Na	CEC
		g kg^{-1}		mg kg^{-1}	Cmol kg^{-1}				
Control	4.6c	0.68^{e}	21.70^{d}	12.23^{e}	2.80^{e}	0.80^{d}	0.07^{e}	0.08^{c}	5.57^{d}
RHB60	5.7b	1.28^{c}	31.10^{a}	15.60^{c}	3.80^{c}	1.20^{cd}	0.24^{c}	0.20^{b}	6.70^{c}
CCB60	5.7b	1.24^{d}	26.90^{c}	14.80^{d}	3.60^{d}	1.80^{c}	0.18^{d}	0.19^{b}	6.92^{c}
PMB60	6.0a	1.52^{b}	30.09^{a}	18.20^{a}	5.80^{a}	3.97^{a}	0.32^{a}	0.28^{a}	10.75^{a}
PDB60	6.2a	1.58^{a}	29.00^{b}	16.50^{b}	5.40^{b}	3.03^{b}	0.31^{b}	0.28^{a}	9.97^{b}

Note: Control = No biochar amendment; RHB60 = Rice husk charred at 250°C for 60 minutes and applied at $10tha^{-1}$; CCB60 = Corn cob charred at 250°C for 60 minutes and applied at $10tha^{-1}$; PMB60 = Poultry manure charred at 250°C for 60 minutes and applied at$10tha^{-1}$; PDB60 = Pig dung biochar charred at 250°C for 60 minutes and applied at $10tha^{-1}$