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Evaluation of Some Agricultural Refuse for Biochar Production and Formulation in Biofertilizer Application

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Abstract: Agricultural refuse is an environmental problem in Nigeria due to open burning and poor disposal. Converting these wastes to biochar provides a dual solution, waste management and soil amendment. This study evaluated Millet straw, Maize stalk, Sorghum, and Sesame for Biochar yield production and Formulation as carrier in Plant growth Promoting Rhizobacteria-based biofertilizer application. The residues were pyrolyzed at 300°C, 400°C, and 500°C in a muffle furnace. Biochar was characterized for yield, Bulk density, Porosity, Water holding capacity, Nitrogen (N), Phosphorus (p), Potassium (k), organic carbon, organic matter pH, Electrical Conductivity (EC) and Cataion Exchange Capacity (CEC) following standard protocols. Results shows Biochar from Millet refuse irrespective of the pyrolysis temperature, consistently gave the overall highest biochar yield in the order. millet > maize > sorghum > sesame at optimum yield 39.2 g - 29.7g, bulk density 0.28- 0,35 and pH 9.6, CEC 45.2 cmol/kg. the coefficient of determination (r^2-values) expressed that temperature accounted for 84.74%, 84.28%, 84.68% and 85.23% of the decrease in biochar mass in millet, maize, sorghum and sesame, respectively. Furthermore, the regression coefficient (b-values) depicts that each 100°C increase in pyrolysis temperature concomitantly caused 16.45g, 15.6g, 14.286g and 12.793g decrease in biochar mass in millet, maize, sorghum and sesame, respectively.Agricultural refuse can be converted to effective biochar-based biofertilizer, reducing waste and improving nutrient use efficiency.

Keywords: *Nutrient, Biochar, Pyrolysis, Biofertilizer Carrier, Waste Management.*

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I. INTRODUCTION

In Nigeria, agriculture is a central part of the economy, with the sector contributing significantly to large amount of agricultural waste (Sahoon et al 2021) due to escalation of agricultural practices and growing population that leads to increased food production (Zubairu et al. 2026). wastes present significant challenges to the country, wide range of agricultural products, including rice, millet, maize, sesame, sourghum, sugarcane and many more are generating substantial amounts of agricultural waste. According to the National Bureau of Statistics (2021), the annual production of agricultural waste in Nigeria is estimated to be in millions of tons, but much of this waste remains largely unutilized, posing environmental and economic challenges (Eziefula et al 2025). At harvest, there is an increased food supply, and subsequently increased agricultural waste generation, burning these agricultural crop residues contributes to global warming, degrading soil fertility increasing particulate in the air (Tagade et al 2021) leading to pollution, increased CO_2 emissions and climate change (Raihan et al 2023). Technologies such as pyrolysis, incineration, anaerobic digestion and gasification can convert these agricultural wastes into energy, addressing both waste management and energy deficits ((Fenta 2024,JO et al 2024) Thermal breakdown of biomass such as wood , straw, or other waste materials and agricultural leftovers at certain temperature produces a supple and inexpensive carbonaceous solid product called Biochar (Sahoon et al 2021). It enhances the chemical, physical, and/or biological qualities of soil, thereby improve crop growth, carbon sequestration, and soil fertility ((Diatta et al. 2020) Borno State is largely dependant on agriculture , mainly centred around millet, sorghum, maize, cowpea, and groundnut and most farming households rely on these staple crops (Zubairu et al. 2026). Biochar is a highly porous material with unique physical and chemical properties produced through the pyrolysis of agricultural residues, Animal manure, leaves, sludge and agro-industrial residues respectively (Gopal et al., 2020) (Liu and Tsai, 2016), (Gurtner et al., 2023), (Mian et al., 2023), and (Alonso-Gomez et al., 2024) have been used as raw material to produce biochar under low or no oxygen conditions. The objective of this study was to present available agricultural waste with high yield for biochar production that is suitable for on-farm applications

II. MATERIALS AND METHODS

- *Sample collection and preparation*

Straws of Millet, Maize, Sorghum, and Sesame were collected and air-dry at open field for10 days, size was reduce by chipping Pyrolyzed at initial weight of 100g of each refuse in muffle furnace at 300°C, 400°C, 500°C for 10min at heating rate of 20°C/min. Cooled and Characterized for Yield = mass Biochar/mass feedstock × 100. (Nath et al 2024)

- *Characterization of Biochar*

Biochar derived from millet were subjected to Characterization at the soil science laboratory faculty of Agriculture university of Maiduguri following standard protocol. Electrical conductivity (EC) (1:20 (w/v)), cation exchange capacity (CEC), and the concentrations of nitrogen (N), phosphorus (P), and potassium (K) in the samples were determined using the protocols by(Diya et al 2023). The estimation of N was carried out using the Kjeldahl steam distillation method. The physical parameters which include bulk density, porosity, water holding capacity and total organic carbon (TOC) content were determined using Piper method (Diya et al 2023)

III. RESULTS

Table 1 shows the result on biochar yield for millet, maize, sorghum and sesame at different at pyrolysis temperatures of 300, 400 and 500ºC. Mean biochar yields among crop biomass x pyrolysis temperature treatment combinations significantly varied from 29.7 - 39.2 g; in which millet gave the overall highest biochar yield at 300ºC, which also was significantly higher than other crops at the other higher temperatures, except at 500ºC versus maize at 300ºC. In general, irrespective of the pyrolysis temperature, biochar yields were consistently in the order millet > maize > sorghum > sesame. Result further indicates that biochar yield in all crops biomass consistently decreased as pyrolysis temperature increased. Fig. 1 shows the effects of pyrolysis temperatures on biochar yields of the four crops biomass; in which the coefficient of determination (r^2-values) expressed that temperature accounted for 84.74%, 84.28%, 84.68% and 85.23% of the decrease in biochar mass in millet, maize, sorghum and sesame, respectively. Furthermore, the regression coefficient (b-values) depicts that each 100ºC increase in pyrolysis temperature concomitantly caused 16.45g, 15.6g, 14.286g and 12.793g decrease in biochar mass in millet, maize, sorghum and sesame, respectively.

Table 2 showed the physical and chemical properties of the Biochars produced from millet straw, maize straw, sorghum straw, and sesame straw sample. Among the four representative sample Millet straw biochar varied significantly with Bulk density of 0.28-0.35g cm^{-3} Porosity (%),Water holding capacity (%),pH, Electrical conductivity(ds m^{-1}), Organic Carbon (%),Organic Matter (%),Total Nitrogen (%),Available Phosphorus (g kg^{-1}), Exchangeable potassium (g kg^{-1}), Calcium (g kg^{-1}), Magnesium (g kg^{-1}), Sodium (g kg^{-1}), CEC (cmolc kg^{-1}), C/N ratio, 68.4-63.5, 285-230, 9.6-8.8, 2.8-2.0, 71.2-62,3, 122.5-107.2, 1.20-1.05, 1.80-1.50, 16.5-13.5, 8.6-7,4, 4.2-3.5, 1.20-0.90, 45.2-36.8, respectively in the order millet > maize > sorghum > sesame. In general millet gave the overall highest except for C/N ratio where millet and sesame gave the same ratio of 59.3

Table 1 Mean Biochar Yield (±SD) for Different Crop Type Biomass and Pyrolysis Temperatures

Crop Type Biomass	Temperature		
	300 ºC	400 ºC	500 ºC
Millet	39.2±0.10a	38.7±0.27b	37.9±0.10c
Maize	37.7±0.10c	36.5±0.10d	35.9±0.10e
Sorghum	34.1±0.10f	33.6±0.17g	32.9±0.10h
Sesame	30.2±0.44i	29.9±0.17ij	29.7±0.35j
SE±	0.1182**		
$LSD_{0.05}$	0.3537		

*** = F-test Significant at 1% Probability Level; $LSD_{0.05}$ for Comparisons of Means for The Same Level of Temperature* = 0.3513*; $LSD_{0.05}$ for Comparisons of Means for Different Levels of Temperature* = 0.3945.

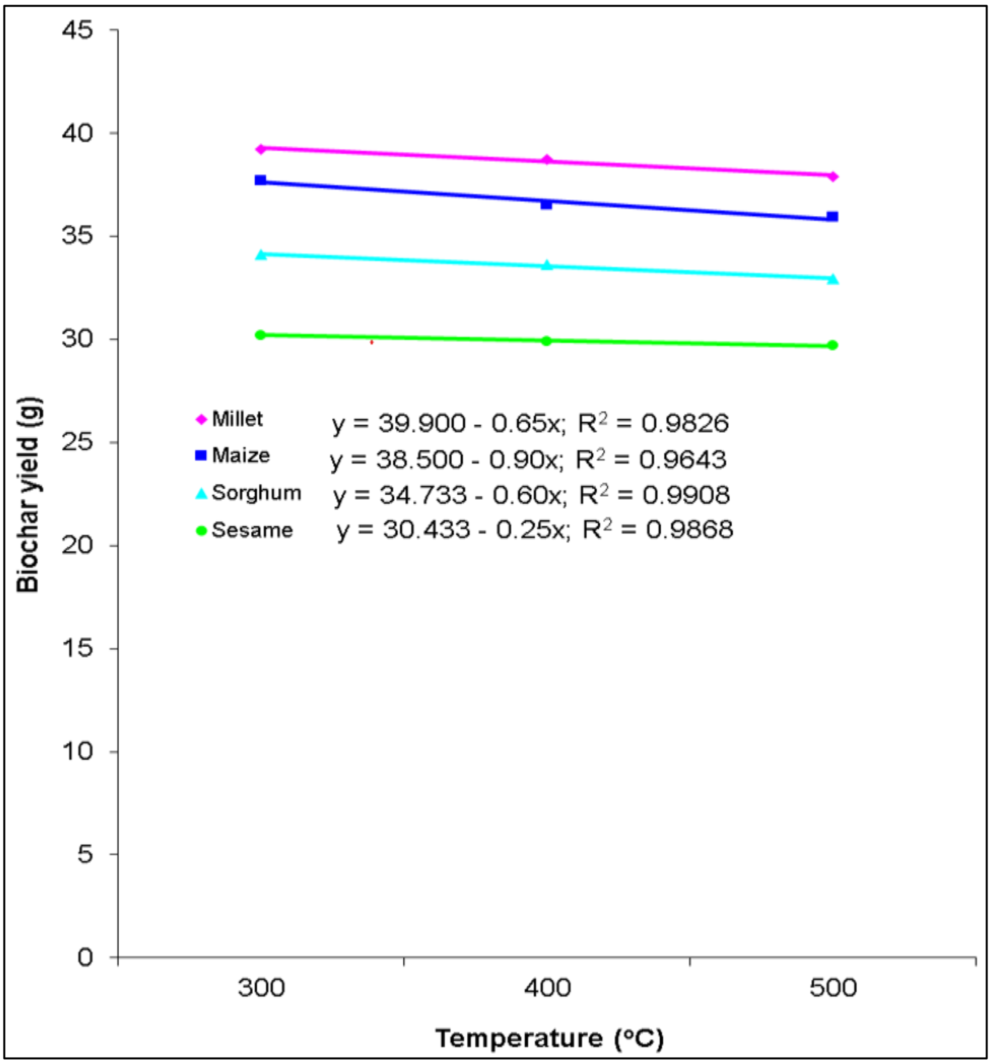

Fig 1 Effects of Pyrolysis Tempratures on Biochar Yields of Four Crops Biomass

Table 2 Typical Physicochemical Properties of Biochar Produced from Different Crop Residues at 500°C

Property	**Millet Straw Biochar**	**Maize Straw Biochar**	**Sorghum Straw Biochar**	**Sesame Stalk Biochar**
Bulk density(g cm^{-3})	0.28	0.32	0.30	0.35
Porosity (%)	68.4	65.7	66.8	63.5
Water holding capacity (%)	285	250	265	230
pH	9.6	9.2	9.0	8.8
Electrical conductivity(ds m^{-1})	2.8	2.3	2.4	2.0
Organic Carbon (%)	71.2	65.8	67.5	62.3
Organic Matter (%)	122.5	113.2	116.1	107.2
Total Nitrogen (%)	1.20	1.10	1.15	1.05
Available Phosphorus (g kg^{-1})	1.80	1.60	1.70	1.50
Exchangeable potassium (g kg^{-1})	16.5	14.2	15.0	13.5
Calcium (g kg^{-1})	8.6	7.8	8.0	7.4
Magnesium (g kg^{-1})	4.2	3.8	4.0	3.5
Sodium (g kg^{-1})	1.20	1.00	1.10	0.90
CEC (cmolc kg^{-1})	45.2	38.5	41.6	36.8
C/N ratio	59.3	59.8	58.7	59.3

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Fig 2 Plate Showing Biochar

IV. DISCUSSION

The biochar quality is assessed on the basis of mass yield of the feedstock, the water holding capacity, its high carbon content, and chemical stability. These qualities are influenced by the type of pyrolysis the residence time, the heating rate of the material, and the type of biomass feedstock (Sedmihradská et al. 2020) temperature range of 450-500ºC was recorded for coconut leaves biochar and lowers 250-350ºC for Eichhornia crassipes biochar. Banana pseudostem Biochar (Diya et al 2023) 350-450ºC was also recorded for coconut palm residues (Gopal et al 2020) Slow pyrolysis of biomass is considered the best method for biochar production at temperatures ranging from 350 to 600 °C (Oyebamiji et al 2025).Different reactors, Ma et al. (2023) demonstrated that pyrolysis temperatures ranging from 400 to 800 °C showed a biochar yield ranging from 42 % to 26 % . the chemical properties of biochar from red pepper stalks showed a significant increase in pH (from 5.8 to 10.3), EC (from 46.0 to 119.5 dS m^{-1}), and T-C (from 47.7 to 63.1%) with rising pyrolysis temperatures, while T-N decreased due to nitrogen volatilization above 300 °C.(Lee et al 2024),(Oyebamiji et al 2025) These findings was in conformity with (Nath et al 2024) despite the different reactors and feedstock utilized in their study. In addition, that the optimum pyrolysis temperature varied from 300°C to 700°C, which supported the present research. Overall, while all biochars satisfied International Biochar Initiative (IBI) quality requirements, millet straw biochar consistently displayed the most desirable physical and chemical characteristics, making it the most promising material for use as a biofertilizer carrier and soil amendment.

V. CONCLUSION

The intensification of agricultural activities has increased the generation of organic waste, creating environmental management challenges. Converting this waste into biochar provides a sustainable solution, producing a carbon-rich material whose properties depend on the feedstock used. Biochar has been shown to improve soil properties and crop growth and is increasingly recognized as an effective carrier for biofertilizers due to its high porosity and nutrient-retention capacity. In particular, biochar produced from millet straw at 500°C possesses desirable physicochemical characteristics and supports the long-term survival of Plant Growth-Promoting Rhizobacteria (PGPR). Therefore, it can serve as a low-cost, environmentally friendly soil amendment and carrier material for biofertilizer formulations, contributing to improved soil fertility, crop productivity, and sustainable agriculture.

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