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# INNOVATIVE BIOCHAR PRODUCTION FROM DIFFERENT AGRICULTURAL WASTES FOR CROP PRODUCTION AND CARBON STORAGE

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## ABSTRACT

This work investigated the performances of three biochars from three agricultural wastes on soil properties, growth and yield of cereal, legume and vegetable crops on an acidic soil. The biochars studied were rice mill husk biochar, saw dust biochar and palm bunch biochar. The biochars were applied at uniform rates of 10t/ha and treatments arranged in a randomized complete block design with three replications. Pre-planting and post-planting soil analysis were determined using standard laboratory procedures. Field and laboratory results were subjected to analysis of variance and significant means were separated using Least significant difference at 5% probability level. Results showed that the biochars increased soil moisture content, soil pH, exchangeable bases, effective cation exchange capacity and base saturation when compared to control. Among the three biochars, palm bunch biochar recorded the highest *Telfairia occidentalis* leaf of 37 as against 14 in control and the number of branches was increased by 40%. At 10 weeks after planting, 10 t/ha palm bunch biochar increased the dry weight of maize by 67%, and maize height by 47%. Application of 10t/ha palm bunch biochar increased the number of groundnut pods by 87%. The three biochars were able to increase the amount of carbon stored when compared to control. Application of 10t/ha saw dust biochar increased the amount of carbon sequestered in the soil by 67%. Therefore, conversion of high carbonaceous agricultural wastes into biochars for soil amendment is an effective measure of increasing soil quality, growth and yield of crops on a weathered soil.

**Keywords**: *Biochars, carbon sequestration, pyrolysis, soil quality*

## INTRODUCTION

Food insecurity is today one of the major challenges facing Nigeria. Previous governments in Nigerian has tried to tackle this problem through different government interventions and agricultural policies. The present administration through its agricultural policies have supported farmers to increase food production by its Agricultural Transformation Agenda (ATA), National Agricultural Technology Innovation Policy (NATIP) and Achor Borrower`s Programme (ABP). These policies and programmes have resulted to production of large quantities of agro-wastes at agro-based industries. However, these agricultural wastes have been reported to constitute environmental hazards and inhabit plant and animal pathogens due to poor utilization and disposal (Onwudike *et al.,* 2019).

The utilization of these agro-wastes such as saw dust and rice mill husk by farmers as soil amendment is still low. This has been partly attributed to its bulkiness, low nutrient quality, high C/N and lignin/N ratios, high cellulose and pectin content and these make them comparatively longer to decompose and release nutrients to crops (Laird *et al.,* 2010). The decomposition of these wastes generates large volume of carbon dioxide into the atmosphere thereby increasing global warming (Van-Zwieten *et al.,* 2010). Again, the carbonaceous nature of saw dust and rice mill husk helps in the immobilization of plant nutrient elements especially nitrogen when applied on soils.

Hence, there is an urgent need to find a way of utilizing these wastes for food production and environmental safety. One of such ways is through innovative pyrolysis of agricultural wastes into biochars. Production of these products will help to reduce soil acidification (Granatstein *et al.,* 2009), improve plant nutrient and increase carbon storage thereby reducing the effects of greenhouse gases in our environment (Shaaban *et al.,* 2018).

The major objective of this research was biochar production through pyrolysis of abundant agricultural wastes for food production and environmental sustainability. Specific objectives were to produce three different biochars using agricultural wastes (rice mill husk, saw dust and palm bunch); To conduct proximate analysis of the biochars. To determine the effects of these biochars on soil properties and yields of one cereal; legume and vegetable crop and to evaluate the effects of these biochars on carbon sequestration for climate change mitigation.

## Materials and Methods

The study was conducted in 2025 planting season at the Teaching and Research Farm, School of Agriculture and Agricultural Technology, Federal University of Technology Owerri, Imo State Nigeria. Imo State is located at latitude 5° 57[1]N and longitude 7° 05[1]E. The area is within the rain forest zone of Nigeria. The climatic data of the year the study was conducted is shown in Figure 1. Geologic materials of the area consist of coastal sediments origin with soils classified as Ultisol according to USDA and Acrisol according to FAO/UNESCO classification system. Low soil organic matter, low activity clay, poor soil aggregation and low pH are some of the soil related constraints affecting the fertility and productivity of soils in the area (Onyegbule *et al.,* 2023). About 80% of the people are subsistent farmers. During dry seasons, fish farmers use fish pond waste water to irrigate their vegetable farmers.

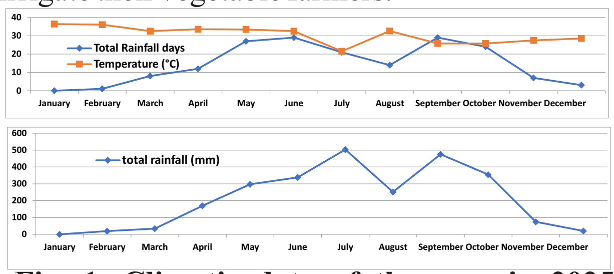



**Fig. 1. Climatic data of the area in 2025 (NIMET Report)**

The project was phased into the following stages: Sourcing of agro-wastes, biochar drum fabrication, pyrolysis process, proximate analysis, and field experimentation. Agricultural wastes used in the study were rice mill husk, palm bunch and saw dust. These materials were sourced from timber markets, rice mill industries and palm plantation enterprise within south-eastern Nigeria. About 1000kg of these materials were transported to Owerri for pyrolysis. Three cylindrical metal drums each measuring 5m height and 4m in diameter were fabricated for the pyrolysis. The materials were pyrolyzed at 200°C under limited oxygen. After pyrolysis, the biochars were air dries at room temperature. Samples of the biochars were taken to the Laboratory for proximate analysis.

### Field experimentation

To establish the effects of biochar on food production, field trials were conducted to evaluate the effects of these biochars on the growth and yield of a cereal (maize), legume (groundnut) and vegetable (*Telfairia occidentalis*). A 480m$^2$ fallow land was cleared, stumped and mapped out into four treatment plots measuring 4m$^2$ with 2m between plots and 2 m between blocks. The treatments applied were 10t/ha of each saw dust biochar, rice mill husk biochar, palm bunch biochar and control plot without biochar application. The experiment was arranged in a randomized complete block design and treatments replicated four times. Pre-planting and post planting analysis was conducted before the study and 12 weeks after biochar application. Effects of the treatments on crop growth were measured at two weeks interval while the yields were measured at 12 weeks after treatment application. The three experiments were conducted simultaneously.

### Laboratory analyses and data interpretation

Sand, silt and clay fractions were determined using hydrometer method as described by Gee and Or (2002). Bulk density and total porosity were determined with core sampler according to Grossman and Reinsch (2002). Soil pH was determined using glass electrode pH meter (Hendershot *et al.,* 1993). Total nitrogen content was determined with modified Kjeldhal method according to the procedures of Bremmer and Malvanancy (1982). Phosphorus availability was determined using Bray 1 method as described by Olsen and Sommers (1982). ICP-Mass spectrometer was used to determine exchangeable cations after displacement in I M $NH_4CI$ solution. Total exchangeable acidity was determined trichromatically according to McLean (1982) method using 1 M potassium chloride against 0.05 M Sodium hydroxide. Summation of total exchangeable acidity and total exchangeable bases was used to calculate effective cation exchange capacity. The percentage of the quotient of total exchangeable bases with effective cation exchange capacity gave the percentage base saturation.

Effects of the treatments on carbon storage was determined by measuring the amount of carbon sequestered in the soil using international approved procedure. Results obtained were subjected to analysis of variance using GenSTAT statistical software and significant means was separated using Fishers Least Significant Difference.

# RESULTS AND DISCUSSIONS

## Proximate analysis of the biochars used in the work

The three biochars were alkaline and contained appreciable amounts of organic carbon, nitrogen, phosphorus, and exchangeable base cations. Palm bunch biochar consistently showed the highest pH, available P, K, Ca, and Mg contents, suggesting a greater liming potential and nutrient supply capacity compared with the other biochars (Table 1).

**Table 1: Proximate analysis of the biochars used in the work**

| Properties | Rice mill husk biochar | Saw dust biochar | Palm bunch biochar |
|---|---|---|---|
| pH | 9.54 | 9.11 | 10.42 |
| Organic Carbon (g/kg) | 18.54 | 16.59 | 17.96 |
| Total Nitrogen (g/kg)) | 0.84 | 0.77 | 0.85 |
| Available P (mg/kg) | 23.61 | 22.68 | 25.82 |
| Potassium (g/kg) | 0.68 | 0.85 | 0.89 |
| Calcium (g/kg) | 0.56 | 0.46 | 0.63 |
| Magnesium (g/kg) | 1.64 | 1.78 | 1.85 |
| Sodium(g/kg) | 0.02 | 0.01 | 0.02 |

## Effects of biochars on soil physical properties

Biochar application did not significantly alter soil texture, which is expected since texture is an inherent soil property (Table 2). However, bulk density was significantly reduced, particularly with palm bunch biochar (1.25 gcm$^{-3}$), compared to the control (1.47 g cm$^{-3}$). Correspondingly, total porosity and moisture content increased under all biochar treatments. The reduction in bulk density and increase in porosity and moisture retention can be attributed to the porous structure and low density of biochars, which enhance soil aggregation and water-holding capacity (Onwudike *et al.,* 2016).

**Table 2: Effect of biochars on soil physical properties**

| Treatment | Sand g/kg | Silt g/kg | Clay g/kg | Textural class | BD g/cm$^3$ | TP % | MC g/kg |
|---|---|---|---|---|---|---|---|
| Control | 778 | 89 | 133 | Loamy sand | 1.47 | 44.3 | 211.4 |
| 10t/ha RMHB | 793 | 73 | 134 | Loamy sand | 1.31 | 50.4 | 352.4 |
| 10t/ha SDB | 810 | 76 | 114 | Loamy sand | 1.38 | 47.7 | 304.5 |
| 10t/ha PBB | 783 | 80 | 137 | Loamy sand | 1.25 | 52.7 | 362.3 |
| LSD(0.05) | NS | NS | NS | | 0.11 | 4.67 | 19.23 |

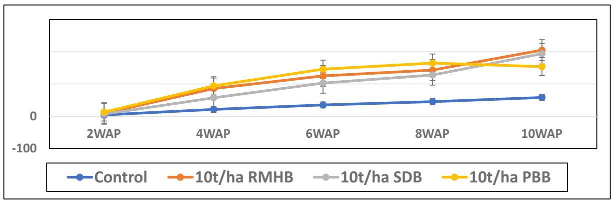
NS= not significant at 0.05 probability level, RMHB= rice mill husk biochar, SDB= saw dust biochar, PBB = palm bunch biochar, BD= bulk density, TP =total porosity, MC= Moisture content

## Effect of biochars on soil chemical properties

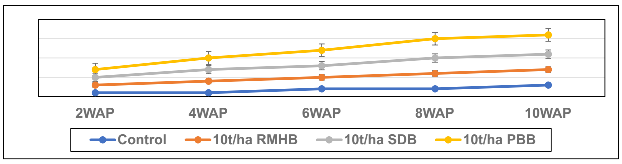
| Treatment | pH $H_2O$ | OC g/kg | TN % | AP Mg/kg | Ca | Mg | K | Na | TEB | TEA | ECEC | BS % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ← | | | Cmol/kg | | | → | |
| Control | 5.19 | 4.55 | 0.14 | 6.43 | 0.16 | 0.15 | 0.15 | 0.18 | 0.64 | 1.54 | 2.18 | 20.35 |
| 10t/ha RMHB | 6.43 | 11.32 | 0.25 | 11.34 | 2.76 | 0.57 | 0.48 | 0.43 | 4.24 | 0.32 | 4.56 | 92.98 |
| 10t/ha SDB | 6.74 | 11.65 | 0.37 | 13.25 | 2.65 | 0.63 | 0.64 | 0.33 | 4.25 | 0.44 | 4.69 | 90.62 |
| 10t/ha PBB | 6.87 | 14.75 | 0.41 | 15.86 | 2.76 | 0.63 | 0.76 | 0.43 | 4.58 | 0.36 | 4.94 | 92.71 |
| LSD(0.05) | 0.35 | 3.24 | 0.06 | 2.43 | 0.09 | 0.03 | 0.03 | 0.12 | 0.27 | 0.21 | 0.11 | 14.24 |

Biochar application significantly improved soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable bases, effective cation exchange capacity, and base saturation compared to the control. (Table 3). Soil pH increased from 5.19 in the control to near-neutral values (6.43–6.87) in amended soils, reflecting the liming effect of the alkaline biochars (Shaaban *et al.,* 2018). This pH improvement likely reduced exchangeable acidity and enhanced nutrient availability.

Organic carbon and total nitrogen increased markedly, with palm bunch biochar recording the highest values, indicating improved soil organic matter status and nutrient supply. Available phosphorus increased more than twofold relative to the control, which is critical for root development and overall plant vigour (Manzoor *et al.,* 2019). The substantial increase in total exchangeable bases and base saturation (above 90% in biochar-treated soils) suggests improved nutrient retention and reduced leaching losses. These improvements collectively created a more favourable soil environment for nutrient uptake and plant growth Diri et al., (2024).




RMHB= rice mill husk biochar, SDB= saw dust biochar, PBB = palm bunch biochar **Fig: 2: Effects of biochars on vine length of *Telfairia occidentalis***




RMHB= rice mill husk biochar, SDB= saw dust biochar, PBB = palm bunch biochar **Fig: 3 Effects of biochars on number of branches of *Telfairia occidentalis***

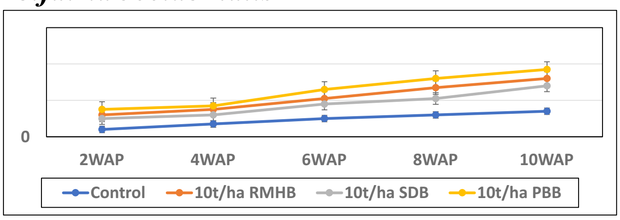
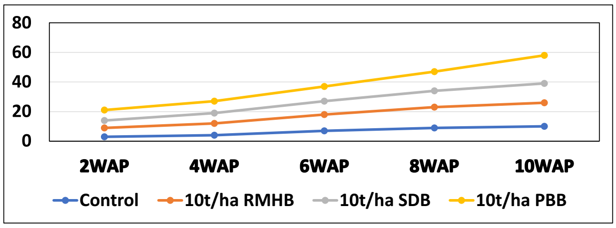



**Fig: 4: Effects of biochars on number of leaves of *Telfairia***

The results demonstrate that biochar application, particularly palm bunch biochar at 10 t ha$^{-1}$, is an effective soil management strategy for improving the productivity of *Telfairia occidentalis* grown on degraded sandy soils. By improving soil structure, moisture retention, nutrient availability, and reducing soil acidity, biochars enhanced plant growth and yield attributes. This observation was in line with Agegnehu et al., (2016) who showed that application of biochar on soil increased the growth and yield of maize. This highlights the potential of biochar as a sustainable amendment for vegetable production in low-fertility tropical soils (Granatstein *et al.,* 2023)

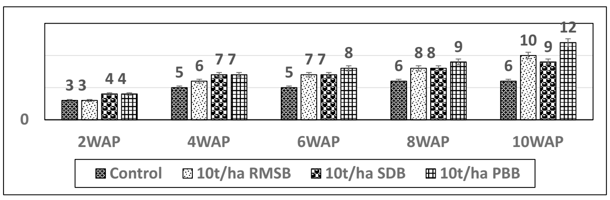
**Effect of biochars on maize and groundnut growth**

Effects of biochars on maize height and groundnut heights are presented in Figures 5 and 6 respectively. The biochars increased the height of maize with significant effect recorded on plots treated with 10t/ha palm bunch biochar. Also, the same treatment recorded the highest number of leaves of groundnut (Figure 7) highest number of groundnut branches (Figure 8) and highest pods of groundnut (Figure 9) when compared to control. The highest number of groundnut pod (23) was recorded on plots amended with palm bunch biochar. This was followed be RMSB. The enhanced performance observed with PBB may be attributed to its favourable physical and chemical attributes, such as increased total porosity, and better nutrient retention, all of which support root development and pod formation (Ojeniyi *et al.,* 2010; Mishra *et al.,* 2023)



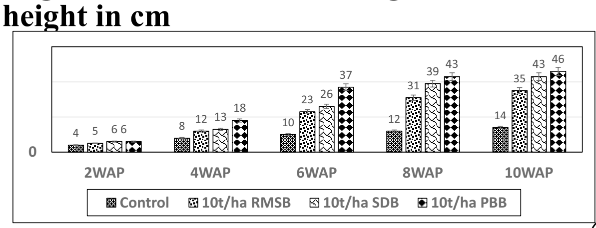

RMHB= rice mill husk biochar, SDB= saw dust biochar, PBB = palm bunch biochar

**Fig. 5. Effects of biochars on maize height (cm)**

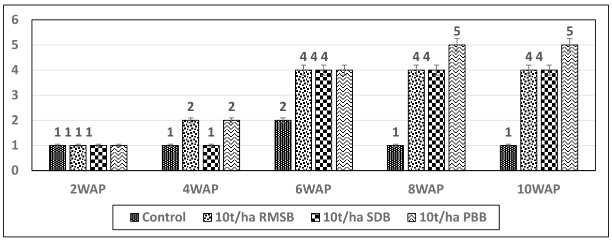



WAP = weeks after planting

**Fig 6: Effect of biochars on groundnut height in cm**

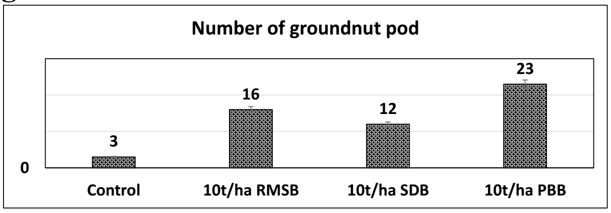



WAP = weeks after planting **Fig 7: Effect of biochars on the number of groundnut leaves**




**WAP = weeks after planting**

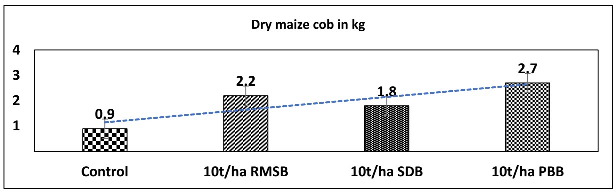
**Fig 8: Effect of biochars on the number of groundnut branches**




RMSB = rice mill husk biochar, SDB = sawdust biochar, PBB = palm bunch biochar

**Fig 9: Effect of biochars on groundnut pod**

Similarly, the biochars recorded the highest maize dry cob as against the control (Figure 10). PBB husk biochar again recorded the highest values (2.7kg), suggesting its strong influence on grain filling and overall yield. The increase in cob dry weight with biochar application could be linked to improved soil fertility (Deshoux *et al.,* 2023, enhanced moisture retention, and increased exchangeable bases in the soil (Olaniyi and Akanbi, 2007).

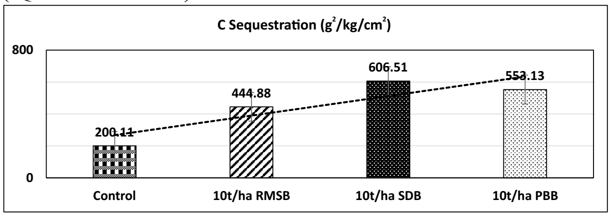



RMHB= rice mill husk biochar, SDB= saw dust biochar, PBB = palm bunch biochar

**Fig. 10. Effects of biochars on dry wet of maize cob in kg**

**Effect of biochars on soil carbon sequestration**

Biochar application resulted in a marked increase in soil organic carbon compared with the control (Figure 11). This confirms the role of biochar as a stable carbon source capable of long-term persistence in soils. Among the treatments, palm bunch biochar (PBB) recorded the highest increase in SOC, followed by sawdust biochar (SDB) and rice mill husk biochar (RMHB). This variation can be explained by differences in biochar pH, organic carbon content, and nutrient composition, with PBB having comparatively higher values. However, biochar application was able to increase soil carbon storage when compared to control plots due to its recalcitrant nature that helps to retain carbon in soil over time (Qi *et al.,* 2021).




RMHB= rice mill husk biochar, SDB= saw dust biochar, PBB = palm bunch biochar

**Fig.11: Effect of biochars on soil carbon sequestration**

## CONCLUSION

Pyrolysis of highly carbonaceous agricultural wastes into biochars for soil amendment is effective in improving soil fertility levels of a degraded soil. Palm bunch biochar performed better than rice mill and saw dust biochar in improving soil quality and increasing the growth and yields of *Telfairia occidentalis*, maize cob and groundnut yields.

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