*Bulgarian Journal of Agricultural Science, 32 (No 1) 2026, 61–67*

# Assessment of chicken feather-based biochar on selected soil properties, growth, and yield of maize (*Zea mays*)

**Nancy Ekene Ebido[a*], Uchenna Mabel Ndubuaku[b] and Chigozie Pascal Umeugokwe[a]**

[a] *Department of Soil Science, Faculty of Agriculture, University of Nigeria, Nsukka, Nigeria*
[b] *Department of Crop Science, Faculty of Agriculture, University of Nigeria, Nsukka, Nigeria*
[*] *Corresponding author:* nancy.ebido@unn.edu.ng

## Abstract

Ebido, N. E., Ndubuaku, U. M. & Umeugokwe, Ch., P. (2026). Assessment of chicken feather-based biochar on selected soil properties, growth, and yield of maize (*Zea mays*). *Bulg. J. Agric. Sci., 32*(1), 61–67

A glasshouse study was conducted to assess the effects of chicken feather-based biochar on some fertility properties, growth, and yield indices of potted maize. The application rates of chicken feather biochar used were: 0 (control), 10, 20, 30, and 40 g/4kg soil, representing 0, 5, 10, 15, and 20 t/ha, respectively. The experiment was laid out in a completely randomized design (CRD) with four replications. The soil's chemical properties were analyzed. Crop growth and yield data collected are: plant height (cm), stem girth (cm), number of leaves, number of cobs/plant, and cob weight/plant (kg) after harvest. Results showed that the application rate of 20 t/ha significantly increased the soil pH, TN and OM by 36.3%, 62.1%, and 62.3%, respectively, while 15 t/ha had the highest significant effect on available P. and CEC (31.18 mg/kg and 8.13 cmol/kg, respectively), when compared with control (5.30 mg/kg and 6.53 cmol/kg, respectively). The highest values of plant height (63.10 cm and 70.43 cm, respectively), and stem girth (3.37 cm and 3.47 cm, respectively), were recorded in the 20 t/ha application rate at 8 and 12 weeks after planting. The yield indices (number of cobs and cob weight/plant) differed significantly ($p \leq 0.05$) among the rates of application. The 20 t/ha gave the highest mean values of the yield indices (1.5 and 0.35 kg, respectively). Amendment of the soil with 20 t/ha chicken feather biochar gave the highest values of the growth and yield indices in maize and can, therefore, be recommended for adoption by maize growers.

*Keywords:* chicken feather biochar; maize performance; soil chemical properties

## Introduction

One of the main reasons for diminishing maize crop production in Southeast Nigeria, is the ultisols' intrinsic low soil fertility and low mineral reserves (Adejumo et al., 2016). The cultivated regions in Southeast Nigeria have less productive potential due to nutrient depletion through erosion and leaching, reduced cation exchange capacity, low base saturation, and increased soil acidity (Onwudike, 2015). To provide food security for Nigeria's fast-growing population, more nutrient input and recycling would be required on the extensively cultivated soils of the country's derived savannah agroecological zones. This can be accomplished with the purposeful promotion of the use of plant and animal wastes for crop production. Using organic wastes, such as biochar, to improve soil has emerged as a practical solution for managing issues with acidity and fertility. Studies have indicated that biochar, which is the byproduct of incompletely burning biomass in the absence of oxygen, improves crop production (Agegnehu et al., 2016; Rafique et al., 2020), as well as soil quality (Martinsen et al., 2015). The application of biochar has been shown in several studies to improve the agronomic performance of tropical soils (Cely et al., 2015; Jin et al., 2015; Sikder and Joarder, 2019).

Feathers are a common by-product of processed chicken, and are produced in significant amounts yearly (each year), worldwide. Approximately, 6% of the mature chicken's live weight could be made up of feathers. They have a high concentration of keratinous protein, which is fibrous and insoluble (Fakhfakh et al., 2011). There are many artistic and practical uses for feathers. Nonetheless, chicken feathers can be utilized as an alternative to organic manure and liming materials, because animal-derived biochars have been shown to improve soil properties such as pH, CEC, water-holding capacity, and organic matter, and to contain elements like nitrogen, phosphorus, calcium, and magnesium (Singh et al., 2010). Therefore, it is necessary to assess the effectiveness of biochar made from chicken feathers as a sort of organic amendment. According to Ibebuchi and Abu (2023), seasonal changes in temperature and rainfall are common environmental factors in Nigeria's derived savannah agroecological zone that might affect the growth of maize. Gaining knowledge on how these environmental elements interact with chicken feather biochar to affect maize growth, can be very beneficial for sustainable agricultural practices in the area. The results of these studies may help change agents and farmers understand the advantages of using chicken feather biochar in agricultural operations, to increase maize yield, while improving soil fertility and health. Additionally, this study might emphasize how crucial it is to use readily available agricultural waste materials, such as chicken feathers, to generate biochar, thereby supporting initiatives for resource sustainability, as well as the management and recycling of waste in the tropics. This study aimed to assess the effects of chicken feather-based biochar on selected soil properties, growth, and yield of maize.

## Materials and Methods

***Soil and its characteristics***

The Department of Soil Science's glass house served as the location for the pot experiment. Auger samples at 0-20 cm depth were collected from the teaching and research farm, Department of Soil Science, University of Nigeria, Nsukka. The sample soil was a weathered, brownish red and coarse textured ultisol, with a sandy loam textural class. It has a strongly acidic pH, with moderate soil organic carbon (SOC) and available phosphorus, the total N is low, and a very low exchangeable potassium content (Ebido et al., 2021).

***Biochar production***

The slaughterhouse in Nsukka town provided the chicken feather feedstock. With the help of a makeshift kiln, made of a cylindrical drum, with a capacity of 10 kg, which was punctured at the sides, the feathers were pyrolyzed (heated with limited oxygen) at a temperature of 550–600°C externally over a closed-chamber furnace. The drum was filled with the feedstocks and sealed snugly with a lid before heating. The drum was continually turned to ensure that the feedstocks burned evenly. Complete burning of the feather was indicated by the brilliant green smoke that emanated from the punctured locations after 45 to 60 minutes.

***Experimental design and treatments***

The experiment was laid out in a completely randomized design (CRD). Twenty plastic pots of 4 kg soil capacity were filled with air-dried and 2-mm sieved topsoil. The biochar was thoroughly mixed with the topsoil in the pots, irrigated with two liters of water, and then planting was done immediately. Afterthat, the potted media were regularly irrigated with 50 mL of water every two days. Five rates of the chicken feather biochar: 0, 10, 20, 30, and 40 g 4 kg soil$^{-1}$, equivalent to 0, 5, 10, 15, and 20 t ha$^{-1}$, respectively (with an average soil bulk density of 1,000 kg m$^{-3}$), were used as the treatment, each replicated four times.

***Sampling and data collection***

As a test crop, the hybrid maize (*Zea mays* L.), variety Oba super II, was acquired from the University of Nsukka's Department of Crop Science. During the three-month trial period, two maize seeds were immediately sowed in each pot at a depth of 3 cm. The soil media were kept consistently moist but not soggy. Hand rouging was used to manually remove weeds once a month. Growth and yield data collected are plant height (cm), stem girth (cm), number of leaves, number of cobs/plant, and grain yield/plant (kg). At 4, 8, and 12 weeks after planting (WAP), one plant from each pot was tagged and sampled, and the height of the plant was measured to the nearest centimeter (cm) from the base of the plant to the base of the unopened apical leaf. The stem girth values of the chosen plant from each pot at 4, 8, and 12 WAP were measured at the stem base point, which is directly above the soil surface. For every plant that was chosen, the number of completely opened, mature, and non-senescing leaves was tallied and then utilized to calculate the number of leaves for each pot. After the maize cobs were harvested at 12 WAP, the fresh weight of the grains per plant and the mean number of cobs per plant were noted for the selected plant. After harvest, soil samples from each pot were collected for analysis of soil chemical properties (pH, total nitrogen, organic matter, and available phosphorus).

***Statistical analysis***

With the use of the software SAS Discovery Edition 4, the collected data were subjected to one-way analysis of variance (ANOVA) for experiments in CRD using a linear model approach. Means that were significant at the 5% probability level were separated using the least significant difference (LSD) test.

## Results and Discussions

***Effects of feather biochar amendment on soil pH, OC, TN, and Av. P***

The results presented in Table 1 represent the effects of the five different rates of feather biochar on some chemical properties of the soil. The results show significant effects ($P \leq 0.05$) of the treatments on soil pH. The soil pH of the control was 4.55 (strongly acidic), while that of the amended soil ranged from 5.26 (moderately acidic) at 5 t/ha to 6.2 (slightly acidic) at 20 t/ha. This shows that biochar is a good amendment with acid-neutralizing capacity that increases soil pH, which is in agreement with other works of Major et al. (2010). This increase in soil pH is attributed to the integration of the highly alkaline nature of the biochar. The treatments had significant ($P \leq 0.05$) effects on the soil's total nitrogen. The total nitrogen of the control was 0.66, while the amended soils were about 62% higher than the control. The study showed that the effects of biochar on soil N were largely positive, where N increased significantly with increasing rates. Increases in N may have resulted from the ability of biochar to lower N leaching (Chan et al.,2007; Van Zwieten et al., 2010). There were significant effects ($P \leq 0.05$) of the treatments on the organic matter content of the soil. The soil organic matter increased by 62%, respectively. It was observed that the increase in SOM increased with increasing rate and increasing WAP. This agrees with the reports of other researchers that biochar, compared to other organic fertilizers, is rich in carbon and not easily biologically degradable. This makes it more stable and gives it the ability to stay longer in the soil (Krull et al., 2006; Lehmann and Rondon, 2006). The results show that the treatments had no significant effect ($P \leq 0.05$) on the phosphorus level of the soil after four, eight, and twelve weeks of incubation. The available phosphorus increased from 5.30 cmol/kg (low) in the control to 31.18 cmol/kg (very high) in 15 t/ha. Phosphorus (P) is a major nutrient essential for plant growth that cannot be replaced by any other element (Neset and Cordell, 2012). Therefore, it is crucial to address its deficiency in the soil by adding phosphorus-rich amendments.

***Exchangeable properties of soils amended with feather biochar***

The results presented in Table 2 show that the treatment had no significant ($P \leq 0.05$) effect on the exchangeable bases of the soil, although the values increased numerically with increasing rates. The results show that the treatments had a significant ($P \leq 0.05$) decreasing effect on the aluminum and hydrogen content of the soil. Biochar was observed to have eliminated aluminum as the hydrogen content decreased from 2.4 cmol/kg in 0 t/ha to 1.6 cmol/kg in 15 t/ha. Aluminum toxicity could be considered a major limiting factor in acidic soils for plant growth and development by directly inhibiting root elongation, thereby interfering with plant nutrient uptake (Singh et al., 2017). The results show that the treatments had a significant effect ($P \leq 0.05$) on the cation exchange capacity of the soil, the cation exchange capacity of the control soil was 6.53 cmol/kg (high), while the amended soil ranged from 7.24 cmol/kg (high) in 10 t/ha to 8.13 cmol/kg in 15 t/ha. The increase of the soil cation exchange capacity as a result of biochar application can be caused by the inherent characteristics of biochar, such as high porosity and surface area as reported by Ndor et al. (2014).

***Interaction effects of chicken feather biochar on maize growth***

When compared to the control, maize cultivated in soil, amended with chicken feather biochar, showed overall gains in growth parameters during the growing season (Figure 1). Chicken feather biochar had a highly significant ($P \leq 0.05$) effect on the growth of maize, which could be a result of the inherent nutrients in the chicken feathers. Studies by Lehmann et al. (2006) and Singh et al. (2010) demonstrated the higher nutritional content of biochar made from animal

**Table 1. Effects of feather biochar rates on some soil chemical properties**

| TRT | pH | pH | Total Nitrogen (TN) | Organic Matter (OM) | Available Phosphorus |
|---|---|---|---|---|---|
| FB | $H_20$ | KCl | % | % | mg/kg |
| 0 t/ha | 4.55 | 4.00 | 0.66 | 1.965 | 5.30 |
| 5 t/ha | 5.26 | 4.60 | 0.87 | 2.586 | 8.53 |
| 10 t/ha | 5.56 | 4.75 | 0.92 | 2.741 | 16.45 |
| 15 t/ha | 5.72 | 4.95 | 0.89 | 2.638 | 31.18 |
| 20 t/ha | 6.20 | 5.20 | 1.07 | 3.189 | 11.47 |
| $LSD_{(0.05)}$ | 0.18 | 0.30 | 0.190 | 0.020 | 15.81 |

*Source*: Authors' own elaboration

**Table 2. Effects of feather biochar rates on some soil chemical properties**

| TRT | $Ca^{2+}$ | $Mg^{2+}$ | $K^{+}$ | $Na^{+}$ | CEC | $H^{+}$ | $Al^{3+}$ |
|---|---|---|---|---|---|---|---|
| FB | Cmol/kg | Cmol/kg | Cmol/kg | Cmol/kg | Cmol/kg | Cmol/kg | Cmol/kg |
| 0t/ha | 2.36 | 0.51 | 0.11 | 0.19 | 6.53 | 2.40 | 1.0 |
| 5t/ha | 2.53 | 0.84 | 0.11 | 0.21 | 7.69 | 2.20 | – |
| 10t/ha | 2.53 | 0.84 | 0.11 | 0.21 | 7.24 | 2.10 | – |
| 15t/ha | 3.04 | 1.18 | 0.12 | 0.22 | 8.13 | 1.60 | – |
| 20t/ha | 2.70 | 1.52 | 0.12 | 0.21 | 7.56 | 1.90 | – |
| $LSD_{(0.05)}$ | NS | NS | NS | NS | 0.85 | NS | 0.168 |

*Source*: Authors' own elaboration

sources. The study conducted by Onwuka and Nwangwu (2016) revealed that poultry-derived biochar had a greater significant ($p \leq 0.05$) impact on okra development when compared to biochar derived from other animal sources. These findings are consistent with the considerable effects of chicken feather biochar on maize growth characteristics.

There were variations among application rates, with 20 t/ha recording the highest mean values for plant height (56.34 cm) and stem girth (3.01 cm), while 15 t/ha recorded the highest values of the number of leaves (10.00). The growth performance of maize was found to increase with an increase in the rates of biochar application, with 20 t/ha having the highest value among the various rates. This was consistent with research by Chan et al. (2008), which showed that crop yield and growth increased as biochar application rates increased.

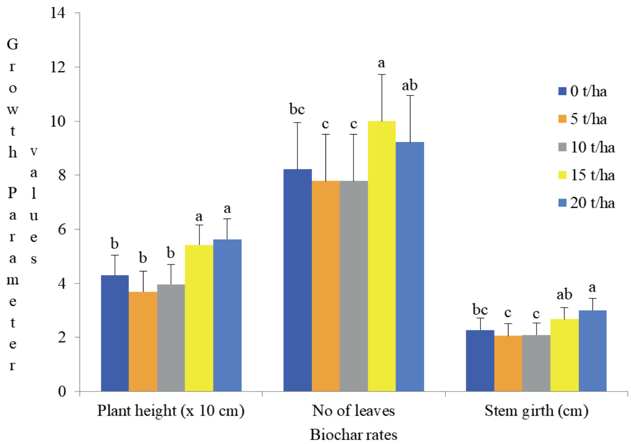



**Fig. 1. Interaction effects of biochar rates on maize growth**
*Source*: Authors' own elaboration

***Effects of biochar on maize plant height across sampling periods***

The results shown in Figure 2 indicate the tallest maize plant at 4, 8, and 12 WAP. During the 8 and 12 WAP sample periods, there were significant ($P \leq 0.05$) effects on plant height due to the varying application rates. With values of 35.49 cm, 63.08 cm, and 70.4 cm at 4, 8, and 12 WAP, respectively, the chicken feather biochar applied at 20 t/ha had the greatest effects. These results were consistent with those of Jeffrey et al. (2011), who reported a high percentage increase in crop growth indices with biochar application at different rates. The high nutrients (potassium, phosphorus, and nitrogen) release potential of biochar at that rate with time may be the cause of the notable improvement in plant growth at 20 t/ha, which is in accordance with the reports of Hossain et al. (2020). At 4 and 8 WAP, the control (0 t/ha) had the lowest mean plant height, while at 12 WAP, the least amount of plant height was produced by 10 t/ha.

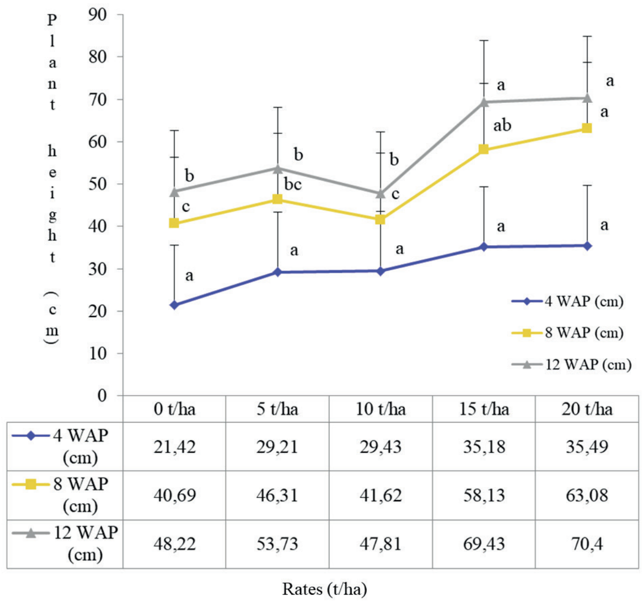
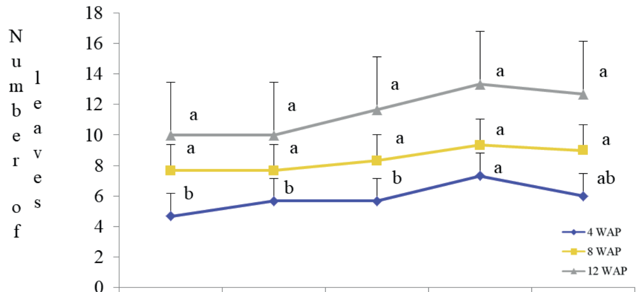



**Fig. 2. Biochar rates on maize plant height (cm)**
**WAP: Weeks After Planting, t/ha = tonnes per hectare**
*Source*: Authors' own elaboration

***Effect of biochar on the number of leaves of maize across sampling periods***

Figure 3 shows the mean number of maize leaves at 4, 8, and 12 WAP. There were no significant differences ($P \leq 0.05$) amongst the rates except at 4 WAP. It was observed that 15 t/ha chicken feather biochar resulted in the highest mean number of maize leaves, with values of 7.33, 9.33, and 13.33 across the sampling periods: 4, 8, and 12 WAP, respectively. This was followed by the 20 t/ha while (control) gave the least mean number of maize leaves. The results obtained amongst the treatment rates agree with the findings of Barrow (2012) and Ippolito et al. (2012), who reported that biochar contained essential nutrients necessary for plant growth, although the resulting nutrient levels depended on the feedstock.



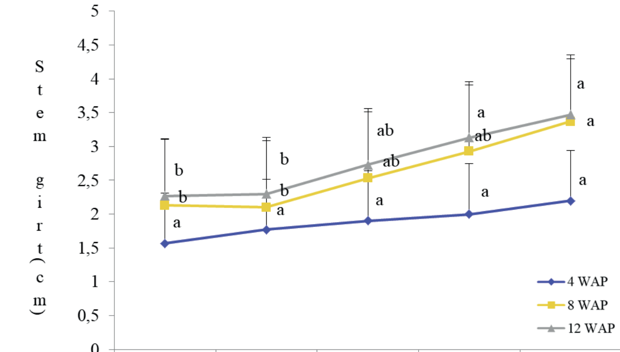

| | 0 t/ha | 5 t/ha | 10 t/ha | 15 t/ha | 20 t/ha |
|---|---|---|---|---|---|
| 4 WAP | 4,67 | 5,67 | 5,67 | 7,33 | 6 |
| 8 WAP | 7,67 | 7,67 | 8,33 | 9,33 | 9 |
| 12 WAP | 10 | 10 | 11,67 | 13,33 | 12,67 |

Rates (t/ha)

**Fig. 3. Biochar rates on the number of leaves of maize plant**
**WAP: Weeks After Planting, t/ha = tonnes per hectare**
*Source*: Authors' own elaboration

***Effect of chicken feather biochar on the stem girth of maize at different sampling periods***

The results in Figure 4 of maize stem girth at 4, 8, and 12 WAP showed significant differences ($P \leq 0.05$) among the biochar rates except at 4 WAP. The mean stem girth rose by 40.13%, 58.22%, and 52.86% throughout the sampling periods (4, 8, and 12 WAP), respectively, with the application of 20 t/ha biochar, and then by 15 t/ha. Notably, the maize stem girth increased in the soil media treated with 15 and 20 t/ha of chicken feather biochar than in the other rates. This aligns with the findings of Zhu et al. (2015), who opined that biochar is a unique type of amendment material due to its high levels of potassium and phosphorus, which are easily assimilated by plants and do not degrade the soil's structure as mineral fertilizers do. This increase in the growth indices of maize plants might be linked to the steady nutrient release by the biochar into the soil media and the availability of the nutrients for plant uptake and growth.




| | 0 t/ha | 5 t/ha | 10 t/ha | 15 t/ha | 20 t/ha |
|---|---|---|---|---|---|
| 4 WAP | 1,57 | 1,77 | 1,9 | 2 | 2,2 |
| 8 WAP | 2,13 | 2,1 | 2,53 | 2,93 | 3,37 |
| 12 WAP | 2,27 | 2,3 | 2,73 | 3,13 | 3,47 |

Rates (t/ha)

**Fig. 4. Effects of biochar rates on the stem girth (cm) of maize**
**WAP: Weeks After Planting, t/ha = tonnes per hectare**
*Source*: Authors' own elaboration

***Effects of biochar rates on the yield components of maize***

The weight of fresh maize (kg) and the mean number of cobs after harvesting are displayed in Figure 5's results. After harvesting, it was found that 20 t/ha of chicken feather biochar produced the highest mean weight of fresh maize (0.35 kg) and number of corn cobs/plant (1.50), followed by 15 t/ha, while control (0 t/ha) had no yield. This demonstrates that biochar derived from animal sources has higher nutrient contents and stabilized organic materials, which assist in raising the soil's fertility and promote crop growth. Consequently, it was shown that crop output was greatly increased by 20 t/ha of biochar. Although the ideal rate of biochar application varies on the particular soil type and crop management, observations of crop development following the application of biochar have consistently shown favorable outcomes (Marjenah et al., 2016). This outcome is consistent with the findings of Major et al. (2010), who found that applying biochar enhances soil fertility, which in turn enhances plant growth.

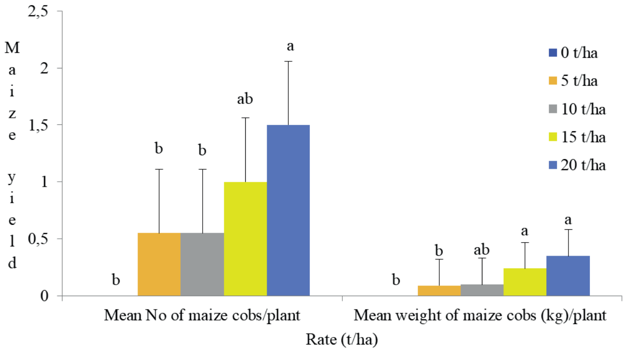



**Fig. 5. Effects of biochar rates on the yield components of maize**

*Source*: Authors' own elaboration

## Conclusion

The study revealed an increase in the growth and yield indices of maize plants with increasing rates of chicken feather biochar application. The 20 t/ha gave the highest values of the growth and yield indices, as well as the soil chemical properties. However, there was a steady increase in the plant height, stem girth, and number of leaves throughout the growth period. The soil's chemical properties increased with increasing application rates. The observed significant increases in soil pH, OM, TN, Available P, CEC, and the growth and yield of the maize plant, due to soil amendment with chicken feather biochar, could be attributed to the high nutrient release from the biochar to the soil, especially at 20 t/ha. Based on the assessment of chicken feather on soil chemical properties and maize production, it is evident that applying chicken feather at the recommended rate of 20 t/ha optimizes soil fertility and enhances maize yield. This conclusion underscores the significant role of chicken feather biochar in improving soil organic matter content, nutrient availability, and overall soil health, thereby contributing to sustainable agricultural practices and maximizing maize production. Therefore, efforts should be made to promote the adoption of chicken feather biochar at its optimum application rate to achieve balanced nutrient management and long-term agricultural productivity.


### *Acknowledgement*

The authors wish to express their gratitude to TETFund, University of Nigeria, Nsukka, for sponsoring this research with the Research project number 35 and reference code TETF/DR&D/CE/UNI/NSUKKA/BR/2020/VOL.1.


## References


**Adejumo, S. A., Owolabi, M. O. & Odesola, I. F.** (2016). Agro-physiologic effects of compost and biochar produced at different temperatures on growth, photosynthetic pigment, and micronutrients uptake of maize crop. *African Journal of Agricultural Research, 11*(8), 661 – 673. DOI:10.5897/AJAR2015.9895.

**Agegnehu, G., Bass, A. M., Nelson, P. N. & Bird, M. I.** (2016). Benefits of biochar, compost and biochar–compost for soil quality, maize yield, and greenhouse gas emissions in a tropical agricultural soil. *Sci. Total Environment, 543*, 295 – 306.

**Barrow, C. J.** (2012). Biochar: Potential for countering land degradation and for improving agriculture. *Applied Geography, 34*, 21 – 28.

**Cely, P., Gascó, G., Paz-Ferreiro, J. & Méndez, A.** (2015). Agronomic properties of biochars from different manure wastes. *Journal of Analytical and Applied Pyrolysis, 111*, 173 – 183. DOI: 10.1016/j.jaap.2014.11.014.

**Chan, K. Y., Van Zwieten, L., Meszaros, I., Downie, A. & Joseph, S.** (2007). Agronomic values of Green waste biochar as a soil amendment. *Australian Journal of Soil Research, 45,* 629 – 634.

**Chan, K. Y., Van Zwieten, L., Meszaros, I., Downie, A. & Joseph, S.** (2008). Using poultry litter biochars as soil amendments. *Australian Journal of Soil Research, 46*, 437 – 444.

**Ebido, N. E., Edeh, I. G., Unagwu, B. O., Nnadi, A. L., Ozongwu, O. V., Obalum, S. E. & Igwe, C. A.** (2021). Rice-husk biochar effects on organic carbon, aggregate stability, and nitrogen-fertility of coarse-textured Ultisols evaluated using Celosia argentea growth. *Sains Tanah Journal of Soil Science and Agroclimatology, 18*(2), 177 – 187. doi.org/10.20961/stjssa.v18i2.56330.

**Fakhfakh, N., Ktari, N., Haddar A., Mnif, I. H., Dahmen, I. & Nasri. M.** (2011). Total solubilisation of chicken feathers by fermentation with a keretinolytic bacterium, bacillus pumilus A1, and the production of protein hydrolytase with high antioxidative activity. *Process Biochemistry, 46*(9), 1731 – 1737.

**Hossain, M. Z., Bahar, M., Sarkar, B., Donne, S., Ok, Y. S., Palansooriya, K. N., Kirkham, M., Chowdhury, S. & Bolan, N.** (2020). Biochar and its importance on nutrient dynamics in soil and plant. *Biochar, 2*, 379 – 420.

**Ibebuchi, C. C. & Abu, I. O.** (2023). Rainfall variability patterns in Nigeria during the rainy season. *Sci. Rep., 13*, 7888. doi.org/10.1038/s41598-023-34970-7.

**Ippolito, J. A., Laird D. A. & Busscher W. J.** (2012). Environmental benefits of biochar. *Journal of Environmental Quality, 41*(4), 967 – 972.

**Jeffery, S., Verheijen, F. G. A., van der Velde, M. & Bastos, A. C.** (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems and Environment, 144*, 175 – 187.

**Jin, Y., Liang, X., He, M., Liu, Y., Tian, G. & Shi, J.** (2015). Manure biochar influence upon soil properties, phosphorus distribution and phosphatase activities: A microcosm incubation study. *Chemosphere, 142*. 10.1016/j.chemosphere.2015.07.015.

**Krull, E., Swanston, C. W., Skjemstad, J. O. & McGowan, J. A.** (2006). Importance of charcoal in determining the age and chemistry of organic carbon in surface soils. *Journal of Geophysical Research, 111*, 1 – 9 G04001.

**Lehmann J., Gaunt J. & Rondon M.** (2006). Bio-char sequestration in terrestrial ecosystems. A review: *Mitigation and Adaptation Strategies for Global Change, 11*(2), 395 – 419.

**Lehmann, J. & Rondon, M.** (2006). Biochar soil management on highly weathered soils in the humid tropics.In: N. Uphoff et al. (eds.), Biological approaches to sustainable soil systems. Florida: CRC Press, Taylor and Francis Group, 517 – 530.

**Major, J., Rondon, M., Molina, D., Riha, S. J. & Lehmann, J.** (2010). Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil, 333* (1–2), 117 – 128.

**Marjenah, K., Purwanti, S. & Sofyan, F. P. M.** (2016). The effect of biochar, cocopeat, and sawdust compost on the growth of two dipterocarps seedlings. *Nusantara Bioscience, 8*, 39 – 44. 10.13057/nusbiosci/n080108.

**Martinsen, V., Alling, V., Nurida, N. L., Mulder, J., Hale, S. E., Ritz, C., Rutherford, D. W., Heikens, A., Breedveld, G. D. & Cornelissen, G.** (2015). pH effects of the addition of three biochars to acidic Indonesian mineral soils. *Soil Sci. Plant Nutr., 61*, 821 – 834.

**Ndor, E., Amana, S. M. & Asadu. C. L. A.** (2014). Effect of biochar on soil properties and organic carbon sink in degraded soil of Southern Guinea Savanna Zone, Nigeria. *International Journal of Plant and Soil Science, 4*(3), 252 – 258.

**Neset, T. S. S. & Cordell, D.** (2012). Global phosphorus scarcity: Identifying synergies for a sustainable future. *Journal of the Science of Food and Agriculture, 92*, 2 – 6.

**Onwudike, S. U.** (2015). Effect of Land Use Types on Vulnerability Potential and Degradation Rate of Soils of Similar Lithology in a Tropical Soil of Owerri, Southeastern Nigeria. *International Journal of Soil Science, 10,* 177 – 185.

**Onwuka, M. I. & Nwangwu, B. C.** (2016). Roles of Biochar Produced from Animal and Plant Wastes on Okra (Abelmoschus esculenta) Growth in Umudike Area of Abia State, Nigeria. *Journal of Agriculture and Sustainability, 9*, 158 – 174.

**Rafique, M., Ortas, I., Rizwan, M., Chaudhary, H. J., Gurmani, A. R. & Hussain Munis, M. F.** (2020). Residual effects of biochar and phosphorus on growth and nutrient accumulation by maize (*Zea Mays* L.) amended with microbes in texturally different soils. *Chemosphere, 238*, 124710. doi.org/10.1016/j.chemosphere.2019.124710.

**Sikder, S. & Joardar, J. C.** (2019). Biochar production from poultry litter as management approach and effects on plant growth. *International Journal of Recycled Organic Waste Agriculture, 8*, 47 – 58. doi.org/10.1007/s40093-018-0227-5.

**Singh, B., Singh, B. P. & Cowie, A. L.** (2010). Characterization and evaluation of biochars for their application as a soil amendment. *Soil Research, 48*(7), 516 – 525.

**Singh, S. Tripath, D. K., Singh, S., Sharma, S., Dubey, N. K. Chauhan, D. K. & Vaculík, M.** (2017). Toxicity of aluminum on various levels of plant cells and organism: a review. *Environmental and Experimental Botany, 137*, 177 – 193.

**Van Zwieten, L., Kimber, S., Morris, S., Chan, K. Y., Downie, A., Rust, J., Joseph, S. & Cowie, A.** (2010). Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant Soil., 327*, 235 – 246.

**Zhu, Q., Peng, X. & Huang, T.** (2015). Contrasted Effects of Biochar on Maize Growth and Nitrogen Use Efficiency, Depending on Soil Conditions. *International Agrophysics, 29*, 257 – 266.

*Received*: **July, 22, 2024**; *Approved*: **October, 10, 2024**; *Published*: **February, 2026**