

# Comparative Effects of Maize Cob Biochar and Inorganic Fertilizer on Soil Properties and Maize Productivity

<sup>1</sup>Ogboji, S., <sup>1</sup>Ajayi, A. J., <sup>2</sup>Akinbuwa, O., <sup>1</sup>Aregbesola, B., <sup>2</sup>Afolabi, J.

<sup>1</sup>Department of Crop Science, Federal College of Agriculture, Akure, Nigeria.

<sup>2</sup>Department of Plant Science and Biotechnology, Adekunle Ajasin University, Akungba Akoko, Nigeria

\*Corresponding author: Ogboji Simon (ogbojisimon2017@gmail.com/+2347015107329)

## Abstract

Declining soil fertility remains a major constraint to sustainable crop production in sub-Saharan Africa. Conventional reliance on inorganic fertilisers has raised concerns about soil health and environmental sustainability. Biochar, a carbon-rich product derived from biomass pyrolysis, has emerged as a promising soil amendment for enhancing soil properties and crop productivity. This study was conducted at the Federal College of Agriculture, Akure, Nigeria, to assess and compare the effects of maize cob biochar and inorganic fertiliser, applied individually and in combination, on soil properties and the performance of maize. The experiment was carried out from April to July 2024 at the Energy Development Unit (EDU) farm, beside REC Road, Federal College of Agriculture, Akure. Maize was sown at a spacing of 75 cm x 40 cm using two seeds per hole. Biochar was applied by broadcasting at 1.5 and 3.0 tonnes per hectare three weeks before planting, while NPK 15-15-15 fertiliser was applied in rings at 100 and 200 kg per hectare four weeks after planting. Treatments included the following: control (no amendment), biochar alone, fertiliser alone, and a combined application of 1.5 t/ha biochar with 100 kg/ha fertiliser, arranged in a randomised complete block design with three replicates. Growth parameters such as plant height, leaf area index, internode length, and stem girth were monitored alongside yield indices including cob weight, grain weight per cob, and number of seeds per cob. Post-harvest soil analysis covered pH, organic carbon, nitrogen, phosphorus, potassium, sodium, calcium, and magnesium content. Results indicated that all treatments significantly enhanced maize growth and yield compared to the control. Biochar alone produced the highest values for plant height (231.69 cm), leaf area index (507.95 cm<sup>2</sup>), stem girth (3.06 cm), and internode length (16.65 cm). Biochar also improved soil pH and organic matter, while NPK fertiliser enhanced immediate nutrient availability. The combined application yielded the most balanced improvement in both growth and soil fertility. The study concludes that integrating maize cob biochar with inorganic fertiliser offers a sustainable and effective strategy for improving maize productivity and long-term soil health.

**Keywords:** biochar, maize growth, soil fertility, NPK fertiliser, integrated nutrient management, sustainable agriculture.

Accepted 17/4/2026

Published 1/6/2026

## 1 INTRODUCTION

Maize (*Zea mays* L.) ranks among the world's most crucial cereal crops, with extensive cultivation in Nigeria, particularly the Southwest, where it forms a dietary staple for millions, alongside uses as livestock feed, processed products (flour, pap, corn flakes, and meal), and economic driver through roasted or boiled consumption (Sasu, 2022). Over 50 species exist globally, differing in colour (white, yellow, and red predominant), texture, grain size or shape; Ojo (2000) identifies it as Nigeria's third key food after sorghum and millet, supplying more than 40% of calories for 1.2 billion in Sub-Saharan Africa (FAO,

2003). Nigeria leads African production at >10 million metric tonnes/year (FAO, 2018), with Ondo State's Akoko North-East/South-West areas yielding profitable gross margins of ₦2,637.80 and net returns of ₦2,141.00 (Furanti, 2005), generating income/foreign exchange over decades.

Production surges notwithstanding, the UN (2010) projects a global population of 9.8 billion by 2050 (Nigeria at 500 million), with the FAO (2010) forecasting a 70% food demand rise (doubling in low-income nations), rendering hunger reduction goals elusive. Soil

management is pivotal for yield boosts amid geometric population growth; soil degradation, nutrient depletion, and low organic matter plague global maize regions (Jatav *et al.*, 2018), yet soils deliver provisioning and regulatory ecosystem services (Dominanti *et al.*, 2014). Agricultural intensification has degraded soils worldwide, necessitating fertility enhancement for limited arable land under population pressure.

Inorganic fertilisers innovated solutions but faltered: subsidy removal bars smallholders (Ganity, 2004) and transport costs burden users (Yeboah *et al.*, 2009), suiting Nigeria's low-income, organic-reliant farmers poorly. Organic matter decomposes to greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O) (Bady, 2016) and destabilises rapidly in humid tropics lacking stabilising minerals (Glasser *et al.*, 2001), impairing nutrient cycling and water/chemical dynamics critical to plant performance.

Biochar, this carbon-rich product from organic biomass pyrolysis and gasification at 300–1000°C in low or no oxygen (Lehman, 2017), has a nutrient profile tied to feedstock/pyrolysis conditions (Atkinson *et al.*, 2010). Variables like temperature, duration, pressure, and post-processing shape properties (Ippoolito *et al.*, 2012) and high porosity surface area boost nutrient retention, cation exchange, and microbes (Lehman & Joseph, 2009). In low-organic soils, it elevates nutrient uptake (Jeffery *et al.*, 2011); maize-specific gains include higher yields via root growth, water/nutrient retention (Glaser *et al.*, 2002; Steiner *et al.*, 2007), and decomposition-resistant carbon storage curbing emissions (Laird *et al.*, 2010). Amazonian Terra Preta's origin (~2,000 years old) inspires; maize cob biochar repurposes waste, blocking waterways/polluting less while sequestering CO<sub>2</sub> (Lehman, 2007).

Southwest Nigeria's maize reliance on inorganic fertilisers risks degradation, leaching or pollution (Schröder *et al.*, 2011), despite biochar's soil structure, microbe and water benefits (Lehmann & Joseph, 2015; Zhang *et al.*, 2016). Research gaps persist in comparative maize cob biochar vs. fertiliser effects on pH, moisture, nutrients, and growth/yield in this high-production zone, beyond isolated studies.

The aim of this study is to assess the comparative impacts of inorganic fertiliser and maize cob biochar as amendments on soil properties and maize (*Zea mays* L.) growth and yield.

The objectives are to compare inorganic fertiliser and maize cob biochar effects on soil properties (e.g., pH, nutrients, organic matter) and also evaluate amendment influences on maize growth parameters (e.g., height, roots) and yield components.

In maize-dominant Southwest Nigeria, locally attuned amendments maximise yields and food security; biochar promotes sustainability, curbing runoff/environmental harm versus fertiliser pitfalls, aligning global shifts to eco-friendly practices.

## 2.0 MATERIALS AND METHODS

### 2.1. Experimental location

The research was carried out close to the Energy Development Unit (EDU) farm, beside REC Road, Federal College of Agriculture, Akure. The annual rainfall ranges between 110 mm and 1500 mm per annum, the relative humidity is 88% and the temperature ranges from 25°C to 30°C.

### 2.2. Field Experimentation

#### 2.2.1 Site preparation

The land was manually cleared, harrowed and ploughed using a cutlass and hoe. The layout operation was done using pegs, rope and meter rulers.

#### 2.2.2 Field Design

A main plot size of 14.5 m x 8 m was measured out, and 4 subplots (sampling units) of 2 m x 3 m were demarcated using a 0.5 m discard between the main plot and subplot and were replicated three times, given a total number of 12 subplots (sampling units). The experiment was laid out in a randomised complete block design (RCBD) with four (4) treatments replicated 3 times to give a total number of twelve (12) sample units as shown below:

No treatment (T<sub>0</sub>), biochar treatment (T<sub>1</sub>), inorganic treatment (T<sub>2</sub>), and biochar/inorganic treatment (T<sub>3</sub>). The treatment combination was done as indicated below.

| BLOCK 1         | BLOCK 2         | BLOCK 3         | BLOCK 4         |
|-----------------|-----------------|-----------------|-----------------|
| MT <sub>0</sub> | MT <sub>1</sub> | MT <sub>2</sub> | MT <sub>3</sub> |
| MT <sub>1</sub> | MT <sub>2</sub> | MT <sub>3</sub> | MT <sub>0</sub> |
| MT <sub>2</sub> | MT <sub>3</sub> | MT <sub>0</sub> | MT <sub>1</sub> |

Where:

Maize with zero treatment (control) (MT<sub>0</sub>), maize treated with biochar only (MT<sub>1</sub>), maize treated with inorganic fertiliser only (MT<sub>2</sub>), and maize treated with combined biochar and inorganic fertiliser (MT<sub>3</sub>).

#### 2.3.1. Biochar source and preparation

The biochar was derived from maize cob that was collected from the Energy Development Unit (EDU) of the

Federal College of Agriculture, Akure. It was dried and crushed before the pyrolysis process.

The pyrolysis, which involved heating of agricultural bio-waste to a high temperature in the absence of oxygen, was done at the IDU (Industrial Design Unit) of the Federal University of Technology Akure. The feedstock was heated at a temperature of 300°C for 6 hours in the complete absence of oxygen and was allowed to cool at room temperature. The cooling process took two weeks so as to avoid oxidation of the biochar. The biochar was collected.

### 2.3.2 Application of Biochar/Inorganic Fertiliser

The biochar was applied 3 weeks before planting at the rate of 1.8 g/6 m<sup>2</sup>, while 0.09 g was combined with fertiliser (at 100 kg/ha), which is equivalent to 1.5 tonnes/ha and 3 tonnes per hectare, respectively, and was applied using the broadcasting method and incorporated into the soil using a hoe. While the NPK 15 15 15 was applied at two different rates because of its combination with biochar. (Integrated nutrient management). In which case 0.06 g of NPK 15 15 15 was applied in 6 m<sup>2</sup> given a plant dose of 0.15 g/stand, which is equivalent to 100 kg/ha. While in a sole application, 0.12g was supplied to a plant population in a 6m<sup>2</sup> land area, given a plant of 0.3g/stands, and it is equivalent to 200kg/ha of fertiliser, and it was applied at 4 weeks after planting.

### 2.4 Planting of test crop

Planting was done on the 25th of April, 2024. Two seeds per hole with plant spacing of 75 cm by 40 cm gives a total number of 40 seedlings in a sample unit of 2 m by 3 m, which is equivalent to 66,667 seedlings/ha.

### 2.5 Crop management

#### 2.5.1 Weed control

A regular weeding was carried out manually using a hoe and cutlass. This practice helps to keep the experimental site clean, control pest and disease manifestation and nutrients' competition with the test crop.

#### 2.5.2 Pests and disease

The fall armyworm is proving to be a threat pest, which threatens farmer productivity and yield forecast. Knowing fully that armyworms attack maize at various stages of its life cycle, especially when there's prolonged rainfall.

Spraying was done using caterpillar force early in the morning or late at night as a preventive measure.

### 2.6 Data collection on crop physiological growth

Data were collected from both plant and soil for analysis.

#### 2.6.1 Plant growth measurement

Data for physiological analysis were collected from different plant parameters within an interval of 4 weeks. Parameters used include plant height, number of leaves per stand, leaf area index, stem girth and internode length.

In each of the measuring periods, five plants were randomly selected for the study. The whole measurement involves the plant height, which was measured with a tape rule; leaf area index, which was measured with a tape rule; number of leaves, which was done by counting; stem girth (cm), which was measured with vernier callipers; and internode length, which was measured with a tape rule.

#### 2.6.2 Data collection on yield

Five plants were randomly selected as well for the determination of yield growth. And parameters like weight of cob, number of seeds per cob and weight of seeds per cob.

### 2.7 Soil determination

Soil samples for analysis were collected pre- and post-planting operation, and soil was collected at the depth of 1-15 cm using a soil auger. These samples will be used for the physiochemical properties of the soil under study.

#### 2.7.1 Soil analysis

A soil study will be carried out on both chemical and physical parameters, which include the following: Chemical properties under consideration include OM, soil pH, K, Na, P, Ca, Mg, exchangeable acidity, CEC and ECEC.

Physical parameters include particle size distribution and bulk density determination.

### 2.8 Data Analysis

Data collected was subjected to analysis of variance (ANOVA), and means were also separated using Tukey HSD at 5% probability.

### 3 RESULTS

#### 3.1 Plant survival and growth

Table 1 reports growth parameters under four treatments: control (no amendment), biochar only, fertiliser only, and the combination of biochar with fertiliser. Survival percentage reached 100% across all treatments, indicating that none of the amendments affected plant establishment. However, the other vegetative traits showed clear and statistically significant differences according to Tukey's HSD test at the 5% level. Plants receiving biochar combined with fertiliser achieved the greatest height (237.63 cm) and leaf area index (571.19 cm<sup>2</sup>), followed closely by the biochar-only treatment (231.69 cm height and 508.0 cm<sup>2</sup> leaf area index). These values markedly exceeded those of the fertiliser-only treatment and the control, where height and

leaf area remained limited. The number of leaves was highest in the combined treatment and biochar-only plots, with both statistically similar and superior to the other two. Stem girth reached its maximum under biochar alone (3.06 cm), with the combined treatment slightly lower but still better than fertiliser alone or the control. Internode length followed a similar pattern, with biochar alone producing the longest internodes (16.65 cm). Overall, treatments containing biochar promoted substantially better vegetative development than fertiliser alone or no amendment, with the combination excelling in height and leaf area while biochar alone proved superior for stem thickness and internode extension. Such responses suggest that biochar contributed to improved structural growth, possibly through better nutrient retention, reduced acidity stress, or enhanced water relations in the poor soil.

**Table 1:** Growth parameters of *Zea mays* under different treatments application.

| Parameters                         | TREATMENT           |                     |                     |                     |
|------------------------------------|---------------------|---------------------|---------------------|---------------------|
|                                    | Control             | Biochar only        | Fertilizer only     | Bio/ Fertilizer     |
| Survival (%)                       | 100.00              | 100.00              | 100.00              | 100.00              |
| Plant height (cm)                  | 132.47 <sup>d</sup> | 231.69 <sup>b</sup> | 206.09 <sup>c</sup> | 237.63 <sup>a</sup> |
| Leaf Area Index (cm <sup>2</sup> ) | 161.9 <sup>d</sup>  | 507.95 <sup>b</sup> | 201.02 <sup>c</sup> | 571.19 <sup>a</sup> |
| Number of leaves                   | 11.6 <sup>b</sup>   | 11.93 <sup>a</sup>  | 11.47 <sup>b</sup>  | 12.73 <sup>a</sup>  |
| Stem girth (cm)                    | 2.06 <sup>d</sup>   | 3.06 <sup>a</sup>   | 2.55 <sup>c</sup>   | 2.94 <sup>b</sup>   |
| Internode length (cm)              | 12.96 <sup>b</sup>  | 16.65 <sup>a</sup>  | 11.47 <sup>c</sup>  | 12.82 <sup>b</sup>  |

Values are means of three replicates. Means with different alphabets in a row differed significantly at 5% level of probability according to Tukey HSD

#### 3.2 Yield parameter

Yield components, which are cob weight, number of seeds per cob, and seed weight per cob, are shown in Table 2. The differences among treatments were large and statistically significant. Biochar applied alone gave the highest values for all three parameters: a cob weight of 375.12 g, 707.8 seeds per cob, and 203.53 g seed weight per cob. These represented substantial increases over the control (approximately 2.3 times for cob weight, 6.8 times for seed number, and 5.4 times for seed weight). The combined biochar and fertiliser treatment performed well but remained statistically lower than biochar alone on

every measure. Fertiliser by itself improved yield over the control yet fell well short of either biochar treatment. The particularly strong response in seed number under biochar alone points to enhanced kernel set, likely linked to better pollination success, reduced stress during reproductive stages, or improved assimilate supply to developing grains. The absence of a synergistic yield advantage when biochar and fertiliser were combined is noteworthy, as many studies report additive or greater benefits from such combinations; here, biochar alone emerged as the most effective single amendment for grain production.

**Table 2:** The effects of soil amendment on the yield of Maize

| Parameters      | TREATMENT           |                     |                     |                     |
|-----------------|---------------------|---------------------|---------------------|---------------------|
|                 | Control             | Biochar only        | Fertilizer only     | Bio/ Fertilizer     |
| <b>CW (g)</b>   | 161.5 <sup>d</sup>  | 375.12 <sup>a</sup> | 280.94 <sup>c</sup> | 313.52 <sup>b</sup> |
| <b>NoSpC</b>    | 104.73 <sup>d</sup> | 707.8 <sup>a</sup>  | 293.67 <sup>c</sup> | 670.5 <sup>b</sup>  |
| <b>SWpC (g)</b> | 37.49 <sup>d</sup>  | 203.53 <sup>a</sup> | 83.39 <sup>c</sup>  | 169.94 <sup>b</sup> |

Values are means of three replicates. Means with different alphabets in a row differed significantly at 5% level of probability according to Tukey HSD. CW = Cob weight, NoSpC = Number of seed per cob, SWpC = Seed weight per cob.

### 3.3 Physicochemical parameter

Table 3 presents the initial physicochemical properties of the experimental soil compared with the biochar material before application. The soil exhibited strongly acidic conditions (pH 4.00 in water), very low organic carbon (0.88%), low total nitrogen (0.10%), and limited available phosphorus (7.23 mg/kg), together with modest exchangeable potassium (0.28 cmol kg<sup>-1</sup>). Its texture was classified as sandy clay loam. In contrast, the biochar showed a near-neutral pH of 6.25, higher organic

carbon (2.16%), considerably more nitrogen (0.77%), elevated available phosphorus (24.36 mg/kg), and especially high exchangeable potassium (6.63 cmol/kg), along with substantial ash content (12.16%). These properties indicate that the biochar possessed strong liming potential and served as a direct source of key macronutrients, particularly potassium, which likely contributed to the observed improvements in plant growth and yield when incorporated into the deficient, acidic soil.

**Table 3:** Physicochemical properties of Soil and Biochar before amendment

| Parameter                               | Soil            | Biochar |
|---|-----------------|---------|
| pH (in water, 1:2)                      | 4.00            | 6.25    |
| Organic carbon (%)                      | 0.88            | 2.16    |
| Organic matter (%)                      | 1.52            | –       |
| Ash                                     | –               | 12.16   |
| Nitrogen (N)                            | 0.10            | 0.77    |
| Available phosphorus (mg/kg)            | 7.23            | 24.36   |
| Potassium (K) (Cmol·kg <sup>-1</sup> )  | 0.28            | 6.63    |
| Sodium (Na) (Cmol·kg <sup>-1</sup> )    | 0.36            | 4.32    |
| Calcium (Ca) (Cmol·kg <sup>-1</sup> )   | 1.70            | 1.36    |
| Magnesium (Mg) (Cmol·kg <sup>-1</sup> ) | 0.80            | –       |
| Particle size                           |                 |         |
| Sand (g·kg <sup>-1</sup> )              | 60.75           | –       |
| Silt (g·kg <sup>-1</sup> )              | 14.02           | –       |
| Clay (g·kg <sup>-1</sup> )              | 25.22           | –       |
| Textural class                          | Sandy Clay Loam | –       |

### 3.4 Post-treatment Soil Properties

Table 4 outlines post-maize cropping soil properties across four treatments. Soil pH stayed low (4.65–4.80) with minimal change from the initial 4.00, despite biochar's alkalinity. Organic carbon and matter peaked in biochar-only plots (0.89% C, 1.52% OM), affirming biochar's enduring boost to soil organics. Available P was highest with fertiliser alone (24.39 mg/kg), nearly matched

by biochar (22.77 mg/kg). Exchangeable bases varied modestly, with elevated Ca and Mg in biochar plots. ANOVA confirmed significant treatment impacts on organic matter, as biochar amendments outperformed control or fertiliser alone. Limited pH gains likely stemmed from low biochar rates, cation leaching in sandy clay loam, soil buffering, or short trial duration.

## 14. Int. J. Soil and Crop Sci.

**Table 4:** Post cropping laboratory analysis of experimental soil

| Experimental Sites/Amendments | Soil pH | Organic Carbon (OC)% | Organic Matter (OM)% | Nitrogen (N)% | Phosphorus (P) | Potassium (K) cmol/kg | Sodium (Na) cmol/kg | Calcium (Ca) cmol/kg | Magnesium (Mg) cmol/kg |
|-------------------------------|---------|----------------------|----------------------|---------------|----------------|-----------------------|---------------------|----------------------|------------------------|
| No Fertilizer                 | 4.78    | 0.69                 | 0.19                 | 0.08          | 11.74          | 0.27                  | 0.36                | 2.40                 | 1.20                   |
| Biochar                       | 4.80    | 0.89                 | 1.52                 | 0.12          | 22.77          | 0.27                  | 0.36                | 3.30                 | 1.30                   |
| Fertilizer                    | 4.68    | 0.80                 | 1.38                 | 0.12          | 24.39          | 0.25                  | 0.34                | 1.90                 | 0.96                   |
| Biochar + Fertilizer          | 4.65    | 0.81                 | 1.40                 | 0.11          | 21.90          | 0.24                  | 0.33                | 1.63                 | 0.80                   |

The ANOVA results confirmed significant differences in organic matter ( $p < 0.05$ ), with biochar and biochar + NPK treatments improving organic carbon and organic matter content more than the control and NPK-alone treatment

## 4. DISCUSSION

This study showed that maize cob biochar, used alone or with NPK 15-15-15 fertiliser, markedly improved maize (*Zea mays* L.) growth, yield, and soil properties on acidic sandy clay loam at Federal College of Agriculture, Akure, outperforming the control and sole fertiliser. These results support biochar's role as a sustainable amendment in nutrient-poor, acidic tropical soils, where inorganic fertilisers offer only temporary benefits without fixing low organic matter, acidity, or nutrient retention. Biochar's porous structure, high surface area, and liming effect promote lasting soil health, water holding, and microbial activity, boosting crop resilience in Southwest Nigeria's variable climate.

### 4.1 Effects on Plant Growth Parameters

Biochar-only and combined treatments yielded the tallest plants (231.69 cm and 237.63 cm), highest leaf area index (507.95 cm<sup>2</sup> and 571.19 cm<sup>2</sup>), more leaves, thicker stems (3.06 cm with biochar alone), and longer internodes (16.65 cm with biochar alone), all significantly better than fertiliser-only and control (Table 1). This enhanced vegetative growth stems from improved nutrient availability, reduced acidity stress, and better water retention, fostering root development and assimilate allocation. Comparable findings emerged with maize cob biochar (5–10 t/ha) plus NPS fertiliser in western Ethiopia's acid soils, boosting height, leaf area index, and biomass via higher pH and nutrient retention (Tufa et al., 2022). In Northern Ghana's Guinea savannah, biochar + compost + half-rate fertiliser increased plant height, stem girth, and leaf number over two seasons through elevated pH, available P, N, and SOC (Abdul-Aziz et al., 2025). The combined treatment's slight advantage in height and leaf area here indicates synergy: biochar retains NPK nutrients against leaching in humid tropics, while NPK supplies quick-release nutrition. Yet biochar alone excelled in stem girth and internodes, highlighting its structural perks aligning with reports that it counters drought and nutrient stress better than fertilisers in low-organic soils, following the pattern control: biochar < fertiliser < biochar + fertiliser for growth and soil quality (Faloye et al., 2024). These gains were significant (Tukey HSD,  $p < 0.05$ ) and echo global trends of 20–127% maize trait improvements in degraded tropical soils (pH < 5.0, like this study's initial 4.00) via biochar (Abdul-Aziz et al., 2025; Golla, 2026).

## 4.2 Effects on Yield Components

Yield traits showed a distinct order: biochar alone topped cob weight (375.12 g), seeds per cob (707.8), and seed weight per cob (203.53 g), 2.3 to 6.8-fold higher than control (Table 2). Combined treatment placed second, with fertiliser alone beating control but trailing both biochar options. Biochar boosted kernel set and grain filling through inherent nutrients (K at 6.63 cmol/kg and P at 24.36 mg/kg; Table 3), better pollination, less reproductive stress, and steady assimilate supply. This matches synergies in integrated uses, like biochar + compost + half-rate fertiliser yielding 105.7–127.4% grain increases over control via higher SOC, N, and P in Guinea savannah (Abdul-Aziz et al., 2025). Biochar alone's lead echoes Ethiopian acid-soil trials with 5 t/ha maize cob biochar + full N/P, raising grain yield 24.1%, biomass 33.9%, and grain weight 12.2% over fertiliser alone by curbing acidity and enhancing soil (Tufa et al., 2022; Golla, 2026). No strong additive yield from the combination likely reflects low biochar rates (1.5–3 t/ha) and a short trial, limiting slow-release effects with full NPK. In weathered tropical soils, moderate-rate maize cob biochar often matches or beats sole fertiliser via direct nutrients and lower losses (Frimpong et al., 2021; Yang et al., 2022; Faloye et al., 2024). Full 100% survival across treatments confirms no phytotoxicity, supporting biochar's safety in smallholder integrated management.

## 4.3 Effects on Soil Physicochemical Properties

Post-harvest, biochar-only plots showed topsoil organic carbon (0.89%) and organic matter (1.52%), plus gains in available P (22.77 mg/kg), Ca, and Mg over control and fertiliser only (Table 4). pH rose modestly (4.65–4.80 from initial 4.00) due to biochar's near-neutral pH (6.25) and high ash (12.16%), providing liming; fertiliser alone peaked P (24.39 mg/kg) but ignored organic matter. ANOVA verified significant organic matter effects ( $p < 0.05$ ). These shifts drove crop gains by boosting nutrient cycling and water retention in leach-prone sandy clay loam. Similar patterns appear elsewhere: Ethiopian two-year trials with 5–10 t/ha maize cob biochar + fertilisers cut acidity, raised nutrients, and lifted maize yields as here (Golla, 2026). A modest pH change here ties to low rates, heavy rain leaching, and soil buffering common in short trials where biochar fosters gradual fertility (Khairo et al., 2025; Zhang et al., 2025). Integration retained more nutrients than sole fertiliser, aiding sustained fertility minus inorganic excesses like eutrophication.

## 4.4 General Implications and Recommendations

Biochar-inclusive treatments' strong results highlight integrated nutrient management for sustainable maize in Southwest Nigeria's degraded soils. Biochar recycles

plentiful maize cob waste, sequesters carbon, cuts pollution from burning or waterway clogging, and counters climate effects fitting circular agriculture trends. Though biochar alone shone here, combinations balance immediate and lasting gains, backed by yield-soil links in integrated setups (Faloye et al., 2024). Future work would explore higher rates, long-term residuals, and smallholder economics. Applying 1.5–3 t/ha maize cob biochar, alone or with cutback NPK, boosts yields, soil health, and food security while easing fertiliser reliance amid costs and subsidy issues.

## 5. CONCLUSION AND RECOMMENDATIONS

This study clearly demonstrates that maize cob biochar, applied either alone or in combination with reduced NPK fertiliser, significantly improved soil fertility, maize growth, and yield performance on acidic sandy clay loam soils in Southwest Nigeria. Biochar alone produced the highest yield components, including cob weight (375.12 g), seeds per cob (707.8), and seed weight per cob (203.53 g), while also enhancing stem girth (3.06 cm) and internode length (16.65 cm). In contrast, the combined treatment of biochar (1.5 t ha<sup>-1</sup>) with reduced NPK (100 kg ha<sup>-1</sup>) achieved superior vegetative growth, with the tallest plants (237.63 cm) and largest leaf area index (571.19 cm<sup>2</sup>). Both biochar-inclusive treatments outperformed sole NPK fertiliser and the control, confirming biochar's role as a powerful soil amendment that improves organic carbon, organic matter, and nutrient retention, particularly potassium and phosphorus, while mitigating the environmental drawbacks of excessive synthetic fertiliser use. These findings highlight maize cob biochar as a sustainable, cost-effective, and environmentally friendly strategy for enhancing maize productivity and soil health. By recycling locally available agricultural waste into biochar, farmers can reduce input costs, improve resilience against nutrient depletion, and contribute to climate-smart agriculture. The study underscores the importance of integrated nutrient management, where biochar provides long-term soil fertility benefits and NPK supplies immediate nutrient availability, together creating a balanced system for smallholder maize production in tropical agroecosystems.

### Recommendations

Farmers in maize-dominant regions of Southwest Nigeria should adopt maize cob biochar at moderate rates (1.5–3 t ha<sup>-1</sup>), either alone or in combination with reduced NPK fertiliser (100 kg ha<sup>-1</sup>, ~50% of the recommended rate), to maximise yield, improve soil fertility, and lower fertiliser costs. Also, policymakers and extension services should promote biochar production from maize cobs as a sustainable waste management and soil fertility strategy,

integrating it into national agricultural programmes. In addition, future research should prioritise multi-season and long-term trials to evaluate residual effects of biochar on soil fertility, crop performance, and carbon sequestration, and studies should also investigate higher biochar application rates, economic feasibility for smallholder farmers, and the influence of biochar on soil microbial dynamics across diverse agro-ecological zones in Nigeria.

## REFERENCES

- Abdul-Latif Abdul-Aziz, A., Abukari, I. A., Galadima, M. M. and Abdulai, R. (2025). Biochar effects on soil properties and yield of maize in Northern region, Ghana. *Discover Agriculture*, 2, Article 71.
- Abdul-Latif Abdul-Aziz, A., Haruna, A. and Baako, A. Y. (2025). Integrating biochar, compost, and chemical fertilizer improves maize yield and soil health in the guinea savannah: Evidence from two cropping seasons in Northern Ghana. *Scientific Reports*, 15, Article 31886. <https://doi.org/10.1038/s41598-025-31886-2>
- Atkinson, C. J., Fitzgerald, J. D., and Hipps, N. A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: A review. *Plant and Soil*, 337(1-2), 1-18.
- Bady, R. (2016). Impact of organic matter decomposition on greenhouse gas emissions. *Journal of Environmental Science*, 29(3), 123-135.
- Dominanti, E., Patterson, M., and Mackay, A. (2014). A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological Economics*, 69(9), 1858-1868.
- Faloye, O. T., Ajayi, A. E., Kamchoom, V., Akintola, O. A. and Oguntunde, P. G. (2024). Evaluating impacts of biochar and inorganic fertilizer applications on soil quality and maize yield using principal component analysis. *Agronomy*, 14(8), 1761. <https://doi.org/10.3390/agronomy14081761>
- Food and Agriculture Organization. (2003). *Food balance sheets: Maize contribution in Sub-Saharan Africa*. Rome: Food and Agriculture Organization of the United Nations.
- Food and Agriculture Organization. (2010). *How to feed the world in 2050*. Rome: Food and Agriculture Organization of the United Nations.
- Food and Agriculture Organization. (2018). *FAOSTAT: Maize production statistics*. Rome: Food and Agriculture Organization of the United Nations.
- Furanti, A. (2005). Profitability of maize farming in Ondo State, Nigeria. *Agricultural Economics Research Review*, 17(1), 112-120.
- Ganity, T. (2004). The impact of fertilizer subsidy removal on smallholder farmers in Nigeria. *Journal of Agricultural Policy*, 15(3), 210-225.
- Glaser, B., Lehmann, J., and Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – A review. *Biology and Fertility of Soils*, 35(4), 219-230.
- Glaser, B., Lehmann, J., and Zech, W. (2001). Sustainable agriculture in the tropics: Challenges of soil organic matter degradation. *Agriculture, Ecosystems and Environment*, 83(3), 261-276.
- Golla, B., Dechassa, N., Mohammed, W. and Gezahegn, A. M. (2026). Impact of biochar and inorganic fertilizers rates on yield and yield components of maize at Bako western Ethiopia. *Journal of Agriculture and Food Research*, 26, 102698. <https://doi.org/10.1016/j.jafr.2026.102698>
- Ippolito, J. A., Novak, J. M., and Busscher, W. J. (2012). Biochar: A synthesis of its agronomic impact beyond carbon sequestration. *Journal of Environmental Quality*, 41(4), 973-989.
- Jatav, H. S., Singh, R., and Sharma, R. K. (2018). Soil degradation and nutrient depletion: Challenges for maize production. *Journal of Soil Science and Plant Nutrition*, 18(2), 456-467.
- Jeffery, S., Verheijen, F. G. A., van der Velde, M., and 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(1), 175-187.
- Khairo, A. M., Farhan, M. J. and Islam, K. R. (2025). Compost and biochar amendments enhanced the growth, yield, nutrient uptake, nitrogen- and water-use efficiency of irrigated corn. *Communications in Soil Science and Plant Analysis*, 56(18), 3142–3158. <https://doi.org/10.1080/00103624.2025.2557385>
- Laird, D. A., Brown, R. C., Amonette, J. E., and Lehmann, J. (2010). Review of the pyrolysis platform for coproducing bio-oil and biochar. *Biofuels, Bioproducts and Biorefining*, 3(5), 547-562.
- Lehmann, J. (2007). Bio-energy in the black. *Frontiers in*

*Ecology and the Environment*, 5(7), 381-387.

Lehmann, J. (2017). Biochar for environmental management: Science, technology and implementation. *Earthscan*.

Lehmann, J., and Joseph, S. (2015). Biochar for environmental management. In *Biochar for Environmental Management: Science, Technology and Implementation* Routledge (pp. 1-12).

Lehmann, J., and Joseph, S. (2009). Biochar for environmental management: An introduction. In J. Lehmann and S. Joseph (Eds.), *Biochar for Environmental Management: Science and Technology* Earthscan (pp. 1-12).

Ojo, M. O. (2000). Economic analysis of maize production in Nigeria. *Journal of Agricultural Economics*, 12(2), 45-56.

Sasu, M. (2022). Maize utilization and processing in Nigeria. *Journal of Food Science and Technology*, 34(1), 78-89.

Schröder, J. J., Neeteson, J. J., Oenema, O., and Struik, P. C. (2011). Nutrient management strategies for sustainable maize production. *Agronomy Journal*, 103(1), 1-6.

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., de Macêdo, J. L. V., Blum, W. E. H., and Zech, W. (2007). Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly

weathered Central Amazonian upland soil. *Plant and Soil*, 291(1-2), 275-290.

Tufa, A., Hunduma, A., Hasan, M. N. S., Asefa, F. and Nandeshwar, B. C. (2022). Levels of biochar and NPS fertilizer rates on growth, yield component, and yield of maize (*Zea mays* L.) at Guto Gida, western Ethiopia. *Advances in Agriculture*, 2022, Article 5400431. <https://doi.org/10.1155/2022/5400431>

United Nations. (2010). *World population prospects: The 2010 revision*. New York: United Nations Department of Economic and Social Affairs

Yang, W., Feng, G., Jia, Y., Yang, Y., Gao, X., Gao, L. and Qu, Z. (2022). Impact of single biochar application on maize growth and yield under different irrigation regimes. *Frontiers in Plant Science*, 13, Article 1006827. <https://doi.org/10.3389/fpls.2022.1006827>

Yeboah, R., and Agyeman, K. (2009). Transportation challenges in the distribution of agricultural inputs in Nigeria. *Journal of Rural Development*, 22(4), 345-360.

Zhang, Q. (2025). Sustainable effects of nitrogen reduction combined with biochar application on maize yield and soil properties. *European Journal of Agronomy*, 162, Article 127350. <https://doi.org/10.1016/j.eja.2024.127350>

Zhang, X., Bian, R., Hussain, Q., Li, L., Pan, G., and Zheng, J. (2016). Biochar improves maize growth by alleviating soil acidity in tropical soils. *Agriculture, Ecosystems and Environment*, 231, 70-78.