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Research Article

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

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Abstract

Declining soil fertility is a major constraint to sustainable crop production in sub-Saharan Africa, and sole reliance on inorganic fertilizers raises concerns about long-term soil health. This study evaluated the effects of maize cob biochar and NPK fertilizer, applied individually and in combination, on soil properties, growth, and yield of maize (*Zea mays* L.) in Akure, Nigeria. The experiment was conducted using a randomized complete block design with three replicates. Treatments included control, biochar (1.5 and 3.0 t/ha), NPK fertilizer (100 and 200 kg/ha), and a combined application of 1.5 t/ha biochar with 100 kg/ha fertilizer. Growth parameters measured included plant height, leaf area index, internode length, and stem girth, while yield indices and post-harvest soil chemical properties were also assessed. Results showed that all treatments significantly improved maize performance compared to the control. Biochar alone produced the highest growth values and yield components, including cob weight (375.12 g), number of seeds per cob (707.80), and seed weight per cob (203.53 g), compared to the control (161.50 g, 104.73, and 37.49 g, respectively). The combined treatment also recorded high values (313.52 g, 670.50, and 169.94 g). Biochar improved soil properties, increasing organic carbon (0.89%) and organic matter (1.52%) relative to the control (0.69% and 0.19%), while fertilizer enhanced available phosphorus (5.39 cmol/kg). The study concludes that integrating maize cob biochar with inorganic fertilizer is an effective and sustainable strategy for improving soil fertility and maize productivity.

Keywords

Maize (*Zea mays* L.), Biochar, NPK Fertilizer, Soil Fertility, Crop Yield

1. Introduction

Maize (*Zea mays* L.) is one of the most widely cultivated cereal crops worldwide and serves as a staple food for millions of people. It is consumed as staple food in Nigeria, accounting for about 43% calorie in the diet of an average Nigerian [1]. Originating from Central America, maize has spread across diverse agro-ecological zones due to its wide adaptability [2]. It is unique among cereal crops because it can be grown under a broad range of climatic conditions, from temperate to tropical environments, making it highly versatile [3]. Beyond its importance as a food crop, maize is also a valuable industrial raw material used in the production of starch, ethanol, animal feed, and a wide range of processed products [4].

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Globally, maize is cultivated in over 170 countries, covering approximately 193 million hectares, with an annual production of about 1,147.7 million metric tonnes [5]. Despite its global significance, maize production is increasingly constrained by soil degradation and declining soil fertility, particularly in southwestern Nigeria. Continuous cropping, low organic matter input, and excessive reliance on inorganic fertilizers have contributed to nutrient depletion, poor soil structure, and reduced water-holding capacity, ultimately limiting crop productivity.

Biochar has recently gained attention as a sustainable soil amendment capable of improving soil health and enhancing crop performance [6, 7]. It is a carbon-rich material produced through the pyrolysis of organic biomass under limited oxygen conditions. Biochar improves soil structure, increases cation exchange capacity, enhances water-holding capacity, and reduces nutrient leaching, making it particularly beneficial in tropical soils that are often characterized by low fertility and high nutrient losses [8].

In low-input agricultural systems common across sub-Saharan Africa, biochar represents a promising and cost-effective strategy for restoring degraded soils and improving crop yields [9]. Previous studies have shown that the application of biochar, especially when combined with nitrogen fertilizers, can improve nitrogen use efficiency, increase nutrient retention, and stimulate soil microbial activity [10, 11]. For instance, Li *et al.* [10] reported a significant increase in maize yield following the combined application of biochar and nitrogen fertilizer, while Sun et al. [11] observed enhanced soil enzyme activities such as urease, which plays a key role in nitrogen cycling.

However, the effectiveness of biochar is influenced by several factors, including soil type, climate, and method of application. Some studies in tropical regions suggest that a single application of biochar can produce residual benefits over multiple cropping cycles. For example, Frimpong *et al.* [12] reported improvements in soil pH, cation exchange capacity, nitrogen content, and organic carbon following a single biochar application in Ghana. Similarly, Mohamed *et al.* [13] found that biochar enhanced nitrogen retention and crop productivity in maize–wheat systems, although in some cases, sole NPK fertilizer performed better depending on environmental conditions.

The method of biochar application also plays a critical role in determining its effectiveness. Yang *et al.* [14] demonstrated that a single application of biochar improved maize yield, water-use efficiency, and fertilizer-use efficiency under varying irrigation regimes. In addition, studies by Skonieski *et al.* [15] and Faloye *et al.* [16] showed that the combined application of biochar and inorganic fertilizer significantly improved soil hydrophysical and chemical properties, resulting in increased maize growth, biomass accumulation, and yield, with higher biomass often indicating improved productivity.

Despite the yield benefits associated with inorganic fertilizers, their continuous use poses environmental risks such as nutrient leaching, soil acidification, and water pollution, and health risks by contaminating soil, water, and the food chain [17]. In southwestern Nigeria, where maize production is prominent, the reliance on inorganic fertilizers without adequate soil management practices has contributed to soil degradation. In contrast, biochar has been shown to improve soil structure, enhance microbial activity, and increase water retention, thereby promoting long-term soil sustainability [18].

Nevertheless, there remains limited information on the comparative performance of locally produced biochar—particularly maize cob biochar—and inorganic fertilizers under the agro-ecological conditions of southwestern Nigeria. Addressing this gap is essential for identifying sustainable and locally adapted soil management practices. Therefore, this study evaluates the comparative effects of inorganic fertilizer and maize cob biochar on soil properties, including pH, nutrient content, and organic matter, as well as their influence on maize growth parameters such as plant height and root development, and ultimately yield performance. Such insights are crucial for improving maize productivity, enhancing food security, and promoting environmentally sustainable agricultural practices in the region.

2. Materials and Methods

2.1. Experimental Location

The research was carried out near the Energy Development Unit (EDU) farm, beside REC Road, Federal College of Agriculture, Akure. The annual rainfall ranges from 110 mm to 1500 mm, the relative humidity is about 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 cutlass and hoe. The layout operation was done using pegs, rope and meter rulers.

2.2.2. Field Design

A main plot measuring 14.5 m × 8 m was established, within which four subplots (sampling units) of 2 m × 3 m were demarcated. A 0.5 m buffer zone was maintained between the main plot and subplots. The experiment was replicated three times, giving a total of 12 subplots (sampling units).

The experiment was laid out in a randomized complete block design (RCBD) with four (4) treatments replicated three (3) times, resulting in a total of twelve (12) experimental units. The treatments were: control (T_0), biochar treatment (T_1), inorganic fertilizer treatment (T_2), and combined biochar and inorganic fertilizer treatment (T_3). Treatment combinations were applied as described below.

Table 1. Treatment combination.

Block 1	Block 2	Block 3	Block 4
MT_0	MT_1	MT_2	MT_3
MT_1	MT_2	MT_3	MT_0
MT_2	MT_3	MT_0	MT_1

Where:

MT_0 = Maize with no treatment (control);
MT_1 = Maize treated with biochar only;
MT_2 = Maize treated with inorganic fertilizer only;
MT_3 = Maize treated with a combination of biochar and inorganic fertilizer.

2.2.3. Biochar Source and Preparation

The biochar was derived from maize cob, that was collected from Energy Development Unit (EDU) of Federal College of Agriculture Akure. It was dried and crushed before pyrolysis process.

The pyrolysis which involved heating of agricultural biowaste to a high temperature in the absence of oxygen was done at IDU (industrial Design unit) of Federal University of Technology Akure. The feedstock was heated at a temperature of 300oC for 6 hours in a complete absent of oxygen and was allowed to cool at a room temperature. The cooling process took two weeks so as to avoid oxidation of the biochar. The biochar was collected.

2.2.4. Application of Biochar/Inorganic Fertilizer

Biochar was applied three weeks before planting at a rate of 1.8 g per 6 m^2 (equivalent to approximately 1.5 t ha^{-1}). In the integrated nutrient management treatment, 0.09 g of biochar was combined with NPK 15:15:15 fertilizer at a rate equivalent to 100 kg ha^{-1} (3 t ha^{-1} of biochar equivalent treatment basis). The biochar was applied using the broadcasting method and incorporated into the soil using a hoe to ensure uniform distribution.

The NPK 15:15:15 fertilizer was applied at two different rates depending on the treatment combination with biochar. In the integrated treatment, 0.06 g of NPK 15:15:15 was applied per 6 m^2 (equivalent to 0.15 g per stand or 100 kg ha^{-1}). In the sole fertilizer application treatment, 0.12 g per 6 m^2 (equivalent to 0.3 g per stand or 200 kg ha^{-1}) was applied. The fertilizer application was carried out four weeks after planting in accordance with standard agronomic practices for maize production.

2.3. Planting of Test Crop

Planting was carried out on 25th April 2024. Two seeds were sown per hole at a spacing of 75 cm × 40 cm, giving a total of 40 seedlings per 2 m × 3 m experimental unit, which is equivalent to approximately 66,667 plants per hectare. This planting density is consistent with recommended agronomic practices for maize cultivation under field conditions.

2.4. Crop Management

2.4.1. Weed Control

Weed control was carried out manually at regular intervals using hoe and cutlass. This practice helped to maintain a weed-free environment, reduce competition for nutrients, water, and light, and minimize the incidence of pests and diseases, thereby promoting optimal crop growth.

2.4.2. Pest and Disease Management

Fall armyworm (*Spodoptera frugiperda*) was identified as a major pest threatening crop performance, particularly during periods of prolonged rainfall. To manage infestation, a recommended insecticide (Caterpillar Force) was applied as a preventive measure either early in the morning or late in the evening to maximize effectiveness and reduce volatilization.

2.5. Data Collection on Crop Physiological Growth

Data were collected from both plant and soil parameters for analysis.

2.5.1. Plant Growth Measurement

Growth data were collected at four-week intervals using randomly selected five plants per treatment unit. The parameters measured included plant height, number of leaves per stand, leaf area index, stem girth, and internode length.

Plant height, leaf area index, and internode length were measured using a measuring tape, while stem girth was measured using a Vernier caliper. The number of leaves was determined by direct counting.

2.5.2. Yield Data Collection

Five plants were randomly selected for yield assessment. Parameters measured included cob weight, number of seeds per cob, and seed weight per cob, which were used to evaluate the productivity response of the crop to treatments.

2.6. Soil Sampling and Analysis

2.6.1. Soil Sampling

Soil samples were collected before planting (pre-planting) and after harvest (post-planting) at a depth of 0–15 cm using a soil auger. The samples were used for laboratory analysis of physicochemical properties to assess changes in soil fertility resulting from the treatments.

2.6.2. Soil Analysis

A Metro pH meter (Model E250) was used to measure the pH of the soil. The hydrometer method was used to measure the size of soil particles [19]. The ammonium saturation method was used to calculate cation exchange capacity (CEC) [20]. Organic matter was determined by the wet oxidation method [21]. Flame photometry was used to estimate K and Na, whereas versenate or EDTA was used to determine Ca and Mg. The Olsen and Mehlich method was used to calculate the amount of phosphorus that was available in the soil [22].

2.7. Data Analysis

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

3. Results

3.1. Plant Survival and Growth

Table 2 reports growth parameters under four treatments: control (no amendment), biochar only, fertilizer only, and the combination of biochar with fertilizer. 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 5% level. Plants receiving biochar combined with fertilizer achieved the greatest height (237.63 cm) and leaf area index (571.19 cm^2), followed closely by the biochar only treatment (231.69 cm height and 508.0 cm^2 leaf area index). These values markedly exceeded those of the fertilizer 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 fertilizer 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 fertilizer 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 2. *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)	132.47d	231.69b	206.09c	237.63a
Leaf Area Index (cm^2)	161.9d	507.95b	201.02c	571.19a
Number of leaves	11.6b	11.93a	11.47b	12.73a
Stem girth (cm)	2.06d	3.06a	2.55c	2.94b
Internode length (cm)	12.96b	16.65a	11.47c	12.82b

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 3. The differences among treatments were large and statistically significant. Biochar applied alone gave the highest values for all three parameters: 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 fertilizer treatment performed well but remained statistically lower than biochar alone on every measure. Fertilizer 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 fertilizer 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 3. The effects of soil amendment on the yield of Maize.

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

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 4 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^{-1}). 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^{-1}), 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 4. Physiochemical 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 (Na)	0.10	0.77
Available phosphorus (mg/kg)	7.23	24.36
Potassium (K) (Cmol-kg-1)	0.28	6.63
Sodium (Na) (Cmol-kg-1)	0.36	4.32
Calcium (Ca) (Cmol-kg-1)	1.70	1.36
Magnesium (Mg) (Cmol-Kg-1)	0.80	_
Particle size		
Sand (g-kg-1)	60.75	_
Silt (g-Kg-1)	14.02	_
Clay (g-kg-1)	25.22	_
Textural class	Sandy Clay Loam	_

3.4. Post-treatment Soil Properties

Table 5 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 fertilizer 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 fertilizer alone. Limited pH gains likely stemmed from low biochar rates, cation leaching in sandy clay loam, soil buffering, or short trial duration.

Table 5. 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	4.77	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 treatments.

4. Discussion

This study showed that maize cob biochar, used alone or with NPK 15-15-15 fertilizer, 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 fertilizer. These results support biochar's role as a sustainable amendment in nutrient-poor, acidic tropical soils, where inorganic fertilizers 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^2 and 571.19 cm^2), more leaves, thicker stems (3.06 cm with biochar alone), and longer internodes (16.65 cm with biochar alone) all significantly better than fertilizer only and control (Table 2). 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 fertilizer in western Ethiopia's acid soils, boosting height, leaf area index, and biomass via higher pH and nutrient retention [23]. In Northern Ghana's Guinea savannah, biochar + compost + half-rate fertilizer increased plant height, stem girth, and leaf number over two seasons through elevated pH, available P, N, and SOC [24]. 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 fertilizers in low-organic soils, following the pattern control < biochar < fertilizer < biochar + fertilizer for growth and soil quality [25]. 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 [26, 27].

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 3). Combined treatment placed second, with fertilizer alone beating control but trailing both biochar options. Biochar boosted kernel set and grain filling through inherent nutrients (K at 6.63 cmol/kg, 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 fertilizer yielding 105.7–127.4% grain increases over control via higher SOC, N, and P in Guinea savannah [24]. 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 fertilizer alone by curbing acidity and enhancing soil [23, 27]. No strong additive yield from combination likely reflects low biochar rates (1.5–3 t/ha) and short trial, limiting slow-release effects with full NPK. In weathered tropical soils, moderate-rate maize cob biochar often matches or beats sole fertilizer via direct nutrients and lower losses [12, 25, 28]. 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 top soil organic carbon (0.89%) and organic matter (1.52%), plus gains in available P (22.77 mg/kg), Ca, and Mg over control and fertilizer only (Table 5). 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; fertilizer 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 + fertilizers cut acidity, raised nutrients, and lifted maize yields as here [27]. Modest pH change here ties to low rates, heavy rain leaching, and soil buffering common in short trials where biochar fosters gradual fertility [29, 30]. Integration retained more nutrients than sole fertilizer, 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 [25]. Future work would explore higher rates, long term residuals, and smallholder economics. Applying 1.5–3 t/ha maize cob biochar, alone or with cut back NPK, boosts yields, soil health, and food security while easing fertilizer reliance amid costs and subsidy issues.

5. Conclusion

This study clearly demonstrates that maize cob biochar, applied either alone or in combination with reduced NPK fertilizer, 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^{-1}) with reduced NPK (100 kg ha^{-1}) achieved superior vegetative growth, with the tallest plants (237.63 cm) and largest leaf area index (571.19 cm^2). Both biochar-inclusive treatments outperformed sole NPK fertilizer 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 fertilizer 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.

6. Recommendations

Farmers in maize dominant regions of Southwest Nigeria should adopt maize cob biochar at moderate rates (1.5–3 t ha^{-1}), either alone or in combination with reduced NPK fertilizer (100 kg ha^{-1}, ~50% of the recommended rate), to maximize yield, improve soil fertility, and lower fertilizer 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 programs. In addition future research should prioritize multi-season and long-term trials to evaluate residual effects of biochar on soil fertility, crop performance, 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.

Abbreviations

NPK	Nitrogen, Phophorus, Potassium
EDU	Energy Development unit

Author Contributions

Ogboji Simon Nwafor: Conceptualization, Investigation, Methodology, Project administration, Resources

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Akinbuwa Olumakinde: Software, Validation, Writing – original draft

Aregbesola Bosede: Investigation, Methodology, Resources

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Conflicts of Interest

The authors declare no conflicts of interest.

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