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Investigating the Effect of Crop Residue Biochar for Heavy Metal-Contaminated Soil Remediation

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Abstract:

This study investigated the effect of Cassava Peel Biochar (CPB) on the remediation of soils contaminated by oil spillage and municipal waste dumpsites, using maize (Zea mays) as a test crop. CPB was incorporated into the soil at four treatment levels (0 g, 50 g, 100 g, and 150 g per planting stand), and maize plants were monitored for vegetative growth over eight Weeks After Emergence (WAE). The growth parameters assessed included the number of leaves, plant height, and stem girth. Data collected were subjected to analysis of variance (ANOVA), and significant means were separated using Least Significant Difference (LSD) at $p \leq 0.05$. Results revealed that the application of CPB significantly enhanced all growth parameters compared to the control. Growth performance increased progressively with increasing levels of CPB, with the 150 g treatment producing the highest number of leaves (14), tallest plants (29.95 cm), and largest stem girth (14.55 mm) at 8 WAE. These findings demonstrate the potential of CPB to improve the growth of maize on contaminated soils by enhancing soil fertility and structure. Therefore, cassava peel Biochar can be recommended as an eco-friendly soil amendment for rehabilitating degraded soils and promoting sustainable crop production.

Keywords — **Cassava peel Biochar, Soil remediation, Oil spillage, Waste dumpsite, Maize growth.**

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I. INTRODUCTION

Farming activities are increasingly threatened by heavy metal contamination of soils, primarily due to indiscriminate waste disposal and oil spills. Common heavy metals found in contaminated soils, according to [1], include lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), and mercury (Hg). These naturally occurring elements have high densities, making them toxic to plants. Alloway (2013) noted that heavy metals enter soils through industrial activities such as mining and oil exploration, agricultural inputs, urban runoff, and hazardous waste disposal.

Specifically, [1], [2], and [3] reported the presence of heavy metals in soils from municipal dumpsites, while [4] observed similar contamination in oil-polluted sites. Reference [5] also observed that, even at low concentrations, these heavy metals are harmful to soils and living organisms, as they disrupt nutrient uptake in crops.

Oil contamination further reduces soil fertility by depleting Nitrogen, Phosphorus, Potassium, Calcium, and Magnesium, while increasing acidity and lowering microbial activity ([6] – [9])

Biochar has been identified as a promising solution for soil contamination, as it reduces heavy metal mobility and bioavailability through adsorption, complexation, precipitation, and pH modification ([10] – [13]). Therefore, this study examined the effect of cassava peel biochar—a residue from cassava processing—on the remediation of oil- and waste-contaminated soils, using maize (Zea mays) as the test crop during its vegetative growth stage.

II MATERIALS AND METHODS

This study examined the vegetative growth of *Zea mays* over eight weeks through a pot experiment conducted at the Crops, Pest, and Soil Laboratory, Department of Agricultural Technology, Federal Polytechnic, Ile-Oluji, Ondo State, Nigeria. A Completely Randomized Design (CRD) with four treatments, each replicated three times, was employed.

Municipal solid waste (MSW) soil samples were collected from the Ile-Oluji dumpsite along Bamikemo/Ipetu Road, while cassava (Manihot esculenta) peels were obtained from the Garri Processing Settlement within the same community. Ile-Oluji is located at latitude 7.1833° N and longitude 4.8667° E, with an estimated population of 180,000 ([14] – [15]). Additionally, oil-spill–contaminated soils were sourced from Aiyetoro Community in Ilaje Local Government Area (latitude 6.10477° N, longitude 4.77756° E) of Ondo State.

All soil samples were collected at a uniform depth of 20 cm, air-dried at 30 °C, homogenized, and sieved to a 2 mm particle size to ensure uniform texture. Before planting, the soil mixtures were analyzed for pH and selected macro- and micronutrient concentrations to establish their baseline properties.

A. *Biochar production*

Cassava peel, a readily available crop residue in the study area, was utilized for Biochar production. The peels were sun-dried and pyrolyzed in an indigenous Biochar kiln developed by [10] at the demonstration farm of the Department of Agricultural Technology, Federal Polytechnic, Ile-Oluji. Pyrolysis was conducted at an average temperature of 350 °C to obtain Cassava Peel Biochar (CPB).

B. *Treatment application*

The experiment involved four levels of CPB amendment, each replicated three times.

T0 (Control): 1 kg soil without CPB
T1: 1 kg soil + 50 g CPB (5% w/w) or 100 t/ha field application rate
T2: 1 kg soil + 100 g CPB (10% w/w) or 200 t/ha field application rate
T3: 1 kg soil + 150 g CPB (15% w/w) or 300 t/ha field application rate

Each treatment was thoroughly mixed with the soil in the pots to ensure even distribution of CPB. It was wet with water and incubated for seven days, after which it was mixed again thoroughly before planting.

C. *Planting of Maize*

SAMMAZ 69 variety of maize (*Zea mays*) seeds were purchased from Agro-Farm Store in Akure, Ondo State. Four seeds were planted per pot. After germination, thinning was done to maintain one healthy seedling per pot. The plants were grown under an adequate water supply and monitored throughout the experimental period.

D. *Data collection*

The following data were collected as dependent variables:

a) Soil fertility (chemical analysis of soil sample to determine the micro and macro elements' level before the commencement of the research using Atomic Absorption Spectrophotometer (AAS))
b) Soil pH (a soil pH instrument was used to measure the pH level of the soil before the research, and that of the organic manure)
c) Day of emergence
d) Number of leaves measured in cm (weekly basis, for 8 weeks)
e) The stem length in cm (weekly basis, for 8 weeks)
f) The stem girth in cm (at the end of week 8)

E. *Data collection*

Data were analyzed using Microsoft Excel (Version 2013) to generate bar charts illustrating the effects of cassava peel Biochar (CPB) on the vegetative growth of Zea mays. A one-way analysis of variance (ANOVA) was performed using IBM SPSS Statistics (Version 26) to determine the significance of CPB effects on maize growth at the 5% probability level ($p \leq 0.05$). A post hoc mean separation test using the Least Significant Difference (LSD) method was subsequently conducted to identify significant differences among treatment means.

III. RESULTS AND DISCUSSION

A. Physical and Chemical Properties of Heavy Metal Contaminated Soil

The analysis of soil samples from the contaminated site (Table I) revealed significant heavy metal accumulation and deterioration of soil quality. The soil pH (7.5) was neutral to slightly alkaline, contrasting with the acidic range (4.5–5.2) reported by [16] for oil spill–affected soils in the Niger Delta. This higher pH may be attributed to alkaline leachates from municipal solid waste, which buffer the acidity typically associated with petroleum hydrocarbons, as corroborated by [17]. Furthermore, the electrical conductivity value (3.0 dS/m) indicated elevated levels of soluble salts, supporting the observation of [18], who noted that contaminated soils often accumulate salts detrimental to plant growth and microbial activity.

The contaminated soil exhibited heavy metal concentrations exceeding permissible limits. Lead (80 mg/kg), cadmium (6.0 mg/kg), chromium (110 mg/kg), nickel (220 mg/kg), copper (180 mg/kg), and mercury (6.0 mg/kg) were all above the WHO/FAO thresholds, aligning with the ranges reported for hydrocarbon-polluted soils by [19] and [18]. Zinc (230 mg/kg) approached the upper safe limit of 300 mg/kg. The nutrient status of the soil was poor, with nitrogen (0.02%) and phosphorus (2 mg/kg) values falling well below agricultural requirements, supporting earlier findings of nutrient depletion in contaminated soils by [18].

TABLE I
PHYSICAL AND CHEMICAL PROPERTIES OF THE HEAVY METAL CONTAMINATED SOIL

Heavy Metal	Value
pH	7.5
Electrical Conductivity (EC)	3.0 (dS/m)
Lead (Pb)	80 (mg/kg)
Cadmium (Cd)	6.0 (mg/kg)
Chromium (Cr)	110 (mg/kg)
Nickel (Ni)	220 (mg/kg)
Copper (Cu)	180 (mg/kg)
Zinc (Zn)	230 (mg/kg)
Mercury (Hg)	6.0 (mg/kg)
Phosphorus	2 (mg/kg)
Bulk Density	1.8 (g/cm^3)
Nitrogen (N)	0.02 %
Porosity	22 (%)
Soil Colour & Odour	Blackish or dark brown, foul-smelling
Soil Structure	Poor aggregation, compacted

Physical properties further reflected severe degradation, characterized by high bulk density (1.8 g/cm^3), low porosity (22%), poor structural stability, and restricted water infiltration. The dark coloration, foul odour, and compacted texture provided additional evidence of hydrocarbon and waste contamination as also observed by [17]. These findings indicate advanced soil deterioration, underscoring the urgent need for remediation interventions such as Biochar application.

B. Physical and Chemical Properties of Heavy Metal Contaminated Soil

The CPB produced in this study exhibited physical and chemical properties suitable for soil amendment and the remediation of heavy metal–contaminated soils, as presented in Table II. It appeared dark brown with a brittle texture, indicating effective carbonization during pyrolysis. The CPB had a low bulk density (0.35 g/cm^3) and high porosity (~70%), consistent with plant-based Biochar's known to enhance soil aeration and water retention according to [20].

CPB produced exhibited high porosity and low bulk density properties that create favourable habitats for soil microorganisms and improve overall soil quality, consistent with the findings of [21]. Its specific surface area (210 m^2 g^{-1}) confirmed a highly porous structure with a strong capacity to adsorb heavy metals, as also reported by [22]. The biochar had a low moisture content (5%) and moderate ash content (12%), which corroborates the similar work of [23], indicating appreciable mineral fractions capable of enhancing soil nutrient status.

TABLE III
PHYSICAL AND CHEMICAL PROPERTIES OF THE CASSAVA PEEL BIOCHAR (CPB)

Property	Value / Observation
Colour	Dark brown
Texture	Brittle
Bulk Density (g/cm³)	0.35
Porosity (%)	70
Surface Area (m²/g)	210
Moisture Content (%)	5
Ash Content (%)	12
pH	9.5
Electrical Conductivity (dS/m)	2.0
Carbon (C) %	65
Nitrogen (N) %	1.0
Phosphorus (P, mg/kg)	850
Potassium (K, mg/kg)	18000
Calcium (Ca, mg/kg)	6500
Magnesium (Mg, mg/kg)	1000

Chemically, the CPB was alkaline (pH 9.5), making it effective for neutralizing acidic soils and reducing metal mobility, consistent with [24]. Its electrical conductivity (2.0 dS m^{-1}) reflected moderate levels of soluble salts that can improve nutrient availability, which also agrees with [25]. Elemental analysis revealed 65% carbon, underscoring CPB's potential for organic carbon enrichment and long-term carbon sequestration as reported by [20]. Nutrient analysis indicated 1.0% nitrogen, 850 mg/kg phosphorus, 18,000 mg/kg potassium, 6,500 mg/kg calcium, and 1,000 mg/kg magnesium. Potassium was the dominant macronutrient, followed by calcium and phosphorus, highlighting CPB's strong fertility improvement potential, as observed by [26] and [27]. These physicochemical properties demonstrate that CPB possesses substantial potential to improve soil structure, enhance nutrient availability, and immobilize heavy metals in contaminated soils.

C. Effect of Cassava Peel Biochar (CPB) on Germination of Maize

The effect of different CPB application rates on maize seed germination was monitored over five days and is presented in Table III. Germination improved progressively with increasing Biochar application. In the control (0 g CPB), only one seed germinated by Day 4, representing a 25% germination rate. This poor result reflects the degraded physical and chemical properties of the contaminated soil, such as low porosity, nutrient deficiency, and heavy metal toxicity. In contrast, Biochar-amended soils exhibited enhanced germination performance. At 50 g CPB, two seeds germinated (50%), while 100 g CPB yielded three germinated seeds (75%). The best response occurred at 150 g CPB, where all four seeds germinated (100%). Seed emergence was also earlier and more uniform in the Biochar-treated soils compared to the control, suggesting that CPB significantly improved the germination environment. These results highlight CPB's effectiveness as a soil amendment for restoring contaminated soils and promoting healthy crop establishment. The cassava peel Biochar (CPB) exhibited high porosity and low bulk density properties that create favourable habitats for soil microorganisms and enhance soil structure and water-holding capacity, consistent with the findings of [21] and [20].

TABLE IIIII
EFFECT OF CPB ON GERMINATION OF MAIZE

Treatment (CPB)	Day 1	Day 2	Day 3	Day 4	Day 5	Total Seeds Germinated	Germination (%)
Control (0 g)	0	0	0	1	0	1	25%
50 g	0	0	2	0	0	2	50%
100 g	0	0	2	1	0	3	75%
150 g	0	0	3	1	0	4	100%

The trend suggests that CPB addition improved soil conditions for germination by enhancing porosity, water retention, and nutrient availability, while also immobilizing toxic heavy metals and reducing their inhibitory effects on seed emergence, consistent with [22] and [20]. Furthermore, the alkaline pH and high potassium and calcium contents of CPB likely contributed to creating a more favourable germination environment.

D. Effect of CPB on the Number of Leaves of Maize Weeks after Emergence (WAE)

The effect of CPB on maize plant growth was evaluated at 2, 4, 6, and 8 weeks after emergence (WAE), and the results are presented in Figure 1. A progressive increase in plant growth parameters was observed with increasing CPB application rates, demonstrating its positive influence on maize growth in heavy metal–contaminated soil. In the control treatment (0 g CPB), the number of leaves increased slowly from 2 at 2 WAE to 6 at 8 WAE. The 50 g CPB treatment recorded 3, 6, 8, and 10 leaves at 2, 4, 6, and 8 WAE, respectively, showing a marked improvement over the control. Further increases were observed with higher Biochar application rates. The 100 g CPB treatment produced 4, 7, 10, and 12 leaves, while the 150 g CPB treatment exhibited the highest values of 5, 9, 12, and 14 leaves across the corresponding growth stages. These results reveal a consistent concentration–response relationship, where increasing CPB levels enhanced plant growth at each stage of assessment.

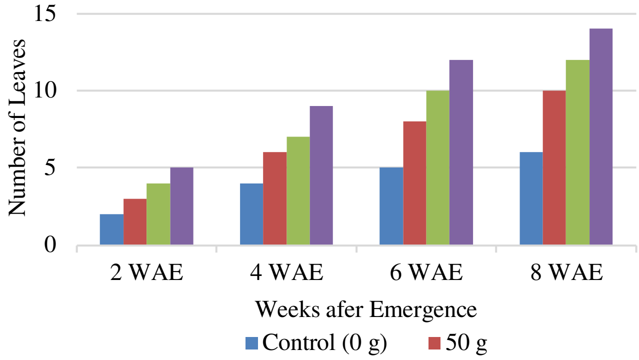

Fig. 1. Effect of CPB on the Number of Leaves of Maize WAE

The observed improvement in growth performance could be attributed to the beneficial physicochemical properties of cassava peel biochar, including its high porosity, low bulk density, improved soil aeration, enhanced water-holding capacity, and provision of essential macronutrients such as potassium, calcium, and phosphorus. These characteristics improve root development and nutrient uptake, leading to healthier plant growth. Similar positive effects of Biochar application on crop performance have been reported by [27] and [26]. Overall, the results indicate that CPB application significantly enhanced maize growth, with the 150 g treatment producing the best response, suggesting that cassava peel biochar can serve as an effective soil amendment for rehabilitating degraded and contaminated soils.

E. Effect of CPB on the Height of Maize Weeks after Emergence (WAE)

The application of CPB significantly influenced plant height in the heavy metal-contaminated soil used for this study. Measurements taken at 2, 4, 6, and 8 WAE are presented in Figure 2. The data showed a progressive increase in plant height with increasing rates of CPB, indicating that Biochar amendment enhanced plant growth performance over time.

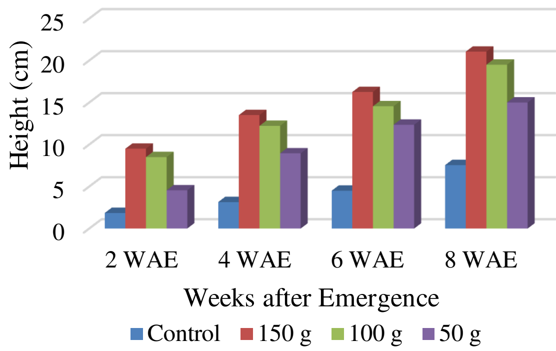

Fig. 2. Effect of CPB on Height of Maize WAE

At 2 WAE, plant height in the control (0 g CPB) was only 1.85 cm, while treatments with 50 g, 100 g, and 150 g CPB recorded 4.55 cm, 8.50 cm, and 9.50 cm, respectively. This early growth response suggests that CPB rapidly improved the soil environment for seedling development. By 4 WAE, plants in the control had grown to 3.15 cm, whereas 50 g, 100 g, and 150 g treatments increased to 8.95 cm, 15.00 cm, and 17.50 cm, respectively. At 6 WAE, plant heights reached 4.50 cm (control), 17.55 cm (50 g), 25.50 cm (100 g), and 26.50 cm (150 g), showing a sharp difference between Biochar-treated soils and untreated soils. By 8 WAE, plants in the control measured only 7.55 cm, while the Biochar treatments reached 22.50 cm (50 g), 24.50 cm (100 g), and 29.95 cm (150 g), with the 150 g CPB treatment producing the tallest plants throughout the experiment. The improved growth performance observed can be attributed to the enhanced soil structure, increased porosity, and improved nutrient availability provided by CPB, which agrees with the works of [20]. The high levels of potassium, calcium, and phosphorus in CPB may have also supported enhanced root and shoot development, which corroborates [27] in a related study.

F. Effect of CPB on the Stem Girth of Maize Weeks after Emergence (WAE)

As shown in Figure 3, at 2 WAE, plants in the control treatment recorded the lowest mean stem girth value (0.85), while those treated with 150 g CPB recorded the highest (3.55). This trend continued as the weeks progressed. By 4 WAE, stem girth growth values increased to 1.85 (control), 3.55 (50 g), 5.58 (100 g), and 6.95 (150 g). The stimulatory effect of Biochar application became more pronounced at 6 WAE, where the growth values were 3.45 (control), 6.45 (50 g), 8.55 (100 g), and 10.11 (150 g). At 8 WAE, the growth performance reached its peak, showing 5.45 (control), 9.55 (50 g), 11.25 (100 g), and 14.55 (150 g).

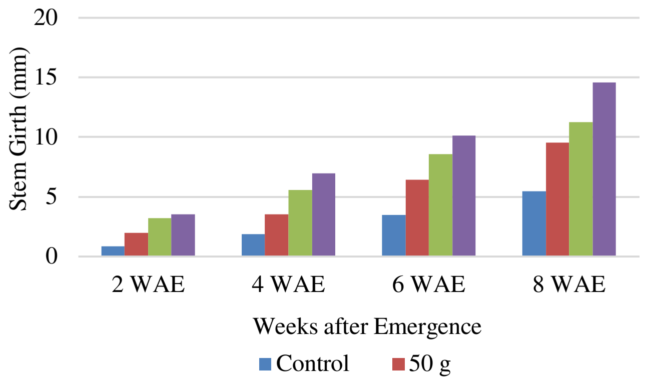

Fig. 3. Effect of CPB on Height of Maize WAE

The results show clearly that the concentration level of CPB affects plant growth, with the highest CPB rate (150 g) consistently producing the tallest plants throughout the experimental period. This suggests that the incorporation of cassava peel Biochar enhanced soil fertility and supported better plant development compared to the untreated control.

G. Analysis of Variance (ANOVA) of the Effect of CPPLB on Maize Growth Parameters

The results of the one-way ANOVA revealed that CPB had a highly significant effect ($p < 0.05$) on the number of leaves, plant height, and stem girth of the test plants at all the growth stages (2, 4, 6, and 8 weeks after emergence) as presented in Table 4. For all three parameters, the F-values were very high and the corresponding p-values were extremely low, confirming that the variation observed among treatments was not due to chance. Specifically, the number of leaves showed F-values ranging from 768.58 at 2 WAE to 7881.97 at 6 WAE, indicating a very strong positive response to Biochar application. Similarly, plant height and stem girth also increased markedly with higher Biochar rates, as reflected by the F-values (4261.81 for height and 1217.19 for girth at 8 WAE).

TABLE IVV
EFFECT OF CPB ON GERMINATION OF MAIZE

Parameter	Time (WAE)	F-value	p-value
Number of Leaves	2 WAE	768.58	3.51×10^{-10}
	4 WAE	3173.75	1.22×10^{-12}
	6 WAE	7881.97	3.22×10^{-14}
	8 WAE	5189.99	1.71×10^{-13}
Plant Height	2 WAE	324.05	1.09×10^{-8}
	4 WAE	520.32	1.66×10^{-9}
	6 WAE	1796.28	1.19×10^{-11}
	8 WAE	4261.81	3.76×10^{-13}
Stem Girth	2 WAE	168.08	1.45×10^{-7}
	4 WAE	226.23	4.51×10^{-8}
	6 WAE	655.80	6.61×10^{-10}
	8 WAE	1217.19	5.62×10^{-11}

**significant at p-value ≤ 0.05*

This statistical analysis confirms that CPB significantly improved plant growth compared to the untreated control. This suggests that Biochar not only enhanced soil properties but also created a more favourable environment for plant development. Following a significant result from the ANOVA, a post-hoc mean separation test using Least Significant Difference (LSD) was conducted to determine which treatment means differed significantly from one another.

G. Post-hoc Test

Post-hoc LSD mean separation as presented on Table V indicated significant differences ($p \leq 0.05$) among treatments for all measured parameters, including number of leaves, plant height, and stem girth, across the various weeks after emergence (WAE). Treatments sharing the same superscript letters within a column were not significantly different, whereas those with different letters differed significantly at $p \leq 0.05$ according to the LSD test.

TABLE V
EFFECT OF CPB ON GERMINATION OF MAIZE

	No of Leaves				Plant Height (cm^2)				Stem Girth (cm^2)			
Treatment (CPB)	2WAE	4WAE	6WAE	8WAE	2WAE	4WAE	6WAE	8WAE	2WAE	4WAE	6WAE	8WAE
Control (0 g)	2.00^{d}	4.00^{c}	5.00^{c}	6.00^{c}	1.85^{c}	3.15^{c}	4.50^{c}	7.55^{c}	0.85^{c}	1.85^{c}	3.45^{c}	5.45^{c}
50 g	3.00^{c}	6.00^{b}	8.00^{b}	10.00^{b}	4.55^{b}	8.95^{b}	17.55^{b}	22.50^{b}	1.95^{b}	3.55^{b}	6.45^{b}	9.55^{b}
100 g	4.00^{b}	7.00^{b}	10.00^{ab}	12.00^{b}	8.50^{a}	15.00^{a}	25.50^{a}	24.50^{a}	3.22^{a}	5.58^{a}	8.55^{a}	11.25^{a}
150 g	5.00^{a}	9.00^{a}	12.00^{a}	14.00^{a}	9.50^{a}	17.50^{a}	26.50^{a}	29.95^{a}	3.55^{a}	6.95^{a}	10.11^{a}	14.55^{a}

At 2 WAE, treatments differed markedly, with 150 g CPB producing the highest number of leaves (5.00^{a}) while the control had the least (2.00^{d}). Similar trends were observed for plant height and stem girth, where 100 g and 150 g CPB were statistically similar ($p < 0.05$) but consistently superior to 50 g and the control. By 8 WAE, plants treated with 150 g CPB attained maximum growth (14.00^{a} leaves, 29.95^{a} cm plant height, and 14.55^{a} cm stem girth), whereas the control remained the lowest. These results indicate that higher CPB rates, particularly 150 g, enhanced vegetative growth significantly compared to lower treatments.

IV. CONCLUSION & RECOMMENDATION

Application of cassava peel Biochar (CPB) significantly enhanced the vegetative growth of the test crop (Zea mays) in terms of number of leaves, plant height, and stem girth compared to the untreated control. The positive response observed followed a concentration pattern, with growth parameters increasing progressively as the level of CPB increased from 50 g to 150 g. The 150 g CPB treatment consistently recorded the highest number of leaves, tallest plants, and greatest stem girth at 8 weeks after emergence (WAE), and these values were significantly higher than those of the control. These findings suggest that CPB is an effective soil amendment that can improve crop growth by supplying essential nutrients and enhancing soil structure.

Cassava peel Biochar (CPB) applied at 150 g per planting stand proved most effective for enhancing vegetative growth of maize under heavy metal–polluted soil conditions. Its use is recommended as an organic amendment to reduce reliance on expensive synthetic fertilizers and support sustainable crop production. Further field studies are needed to examine the effect of this ratio on the yield parameters of the Maize. Likewise the long-term impacts of CPB on soil fertility and crop yield across diverse soil types and seasons. Policymakers and extension services should also encourage the conversion of agricultural wastes, such as cassava peels and cocoa pods, into Biochar to reduce environmental pollution while improving soil productivity.

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