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The Impact of Biochar Derived from Corncobs in Ameliorating Soil Quality of Rice Farm in Dutse, Nigeria

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Abstract

In response to the challenges posed by organic soil contamination, a promising approach involves the application of biochar. This study investigates the effects of biochar derived from corncobs on soil organic matter, organic carbon, and soil microbial biomass carbon through one-factor factorial design experiments. Crushed corncobs were subjected to pyrolysis at 300 °C to produce corncobs-biochar, which was incrementally added to pots containing four different levels of paddy soils. Results indicated a significant enhancement ($p<0.05$) in the physicochemical composition of samples and improved acid degradation upon the addition of corncob-biochar with pH increasing from 1.3 in control to 9.10 in the highest treatment (TP4), along with notable improvements in electrical conductivity, cation exchange capacity, and organic carbon levels. The most effective biochar applications, TP3 and TP4, demonstrated improved nutrient retention and reduced soil acidity. This suggests that incorporating corncob-biochar into the soil can ameliorate acidic conditions and sequester carbon for future ecosystem use. In conclusion, amending soil with corncob-biochar demonstrates a notable enhancement in soil quality. The environmentally friendly application of corncob-biochar could be recommended by offering a sustainable and economically practical strategy for enhancing soil quality, addressing soil degradation, and promoting long-term agricultural productivity.

Keywords: *Biochar, nutrient retention, corncobs, rice farm, soil remediation, sustainable agriculture*

1. Introduction

Globally, food production faces significant threats due to climate change and soil degradation, which are exacerbated by pollution and unsustainable agricultural practices (Davis *et al.*, 2021; Xu *et al.*, 2016). Soil quality plays a pivotal role in determining crop productivity, and its improvement through sustainable practices is essential for addressing food insecurity (Lal, 2015). While soil degradation is a universal concern, rice farms in semi-arid regions like Dutse, Nigeria, experience unique challenges such as low organic matter, nutrient depletion, poor water retention, and the effects of intensive agriculture. These factors collectively reduce productivity and threaten the livelihoods of farmers in the region.

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Food insecurity is a worldwide challenge that disproportionately affects developing nations, where rising populations and decreasing availability of agricultural land, water, and other resources heighten the risk (Ray *et al.*, 2015). Rice farming faces significant challenges due to intensive agricultural practices (Chang *et al.*, 2024; Lehmann *et al.*, 2019) and environmental factors (Ren *et al.*, 2020) such as soil degradation caused by erosion, flooding, nutrient depletion, and salinization, particularly in regions like Sudan Savanna. In this study area, the prevailing climatic conditions, characterized by erratic rainfall and high temperatures typical of Sudan Savannah zones, intensify the degradation of paddy soils, making rice farming increasingly unsustainable. Inadequate irrigation practices, coupled with nutrient-depleted soils, further exacerbate the problem, necessitating innovative solutions to restore soil fertility and enhance crop yield.

Biochar, derived from agricultural residues like corncobs, emerges as a promising solution for addressing these challenges. With its ability to improve soil structure, enhance water retention, and regulate pH (Shen *et al.*, 2024), corncob-derived biochar (Eniola & Oluwole, 2022; Muhammad *et al.*, 2021) offers a sustainable alternative for rehabilitating degraded soils in rice farms (Zhang *et al.*, 2020; Jeffrey *et al.*, 2011). Studies have demonstrated that biochar boosts nutrient availability, enhances microbial activity (Singh et al., 2022), and reduces greenhouse gas emissions, making it a climate-smart strategy for sustainable agriculture (Yuan *et al.*, 2017; Jeffery et al., 2011; Woolf *et al.*, 2010). Its slow nutrient release also decreases dependency on chemical fertilizers, aligning with global goals to reduce agricultural pollution (Lehmann *et al.*, 2022).

This study focuses on assessing the effectiveness of corncob-derived biochar in ameliorating soil quality in rice farms in Dutse, Nigeria. By analyzing its impact on soil properties, water retention, and crop yields, the research aims to provide insights into the potential of biochar as a sustainable solution tailored to the unique challenges faced by rice farmers in this semi-arid region. The findings are expected to contribute to sustainable farming practices and serve as a model for similar agro-ecological zones.

2. Methods

2.1. Study Area

This research utilized paddy soil samples obtained from rice farms with a documented history of rice farming in the Yalwawa area, Dutse, Jigawa State, Nigeria. Dutse serves as the capital city of Jigawa State and also the headquarters of the 28 local government areas comprising the state. The study area is an altitude of 460 meters above sea level, located at Latitudes 11.76° north and Longitude 9.34° east. It is characterized as an urban area that has about 17,129 inhabitants as reported by Adeleye *et al.* (2019).

2.2. Soil Sample Collection and Preparation

A disturbed soil sample was collected from the topsoil (0 - 20 cm depth) of a paddy field, homogenized, and subdivided for standard characterization and a subsequent pot experiment. The sample was air-dried, ground, and passed through a 2 mm sieve to obtain the fine earth fraction, following the procedure described by Nkereuwem *et al.* (2021). The processed soil was stored in polyethylene bags to maintain its integrity until use.

2.3. Production of Corncob Biochar

Corncobs were collected from local farmland, cleaned with deionized water, and air-dried. The corncobs, ranging from 10 to 17 cm in length and 2 - 5 cm in diameter, were carbonized in a furnace at 300 °C following the protocol of Onokebhagbe *et al.* (2018). The resulting biochar was ground and sieved through a 2 mm mesh to ensure uniform particle size, as outlined by Beesley *et al.* (2010). The biochar was then stored in airtight containers until use.

2.4. Experimental Design

The study employed a one-factor factorial design with four treatments, combining varying levels of corncob-biochar (CCB) and paddy soil (PS). Treatments were applied as follows:

a. **Corncob-Biochar (CCB):**

- CCB0: No biochar (control).
- CCB1: 50 g of biochar per pot.
- CCB2: 100 g of biochar per pot.
- CCB3: 300 g of biochar per pot.

b. **Paddy Soil (PS):**

- PS1: 100 g per pot.
- PS2: 150 g per pot.
- PS3: 250 g per pot.
- PS4: 500 g per pot.

This design resulted in sixteen (16) treatment combinations (e.g., CCB0PS0, CCB1PS1, etc.), each replicated twice for a total of thirty-two (32) pots. Each pot had a 3 L capacity with dimensions of 15 cm height and 12 cm diameter.

2.5. Pot Trial and Biodegradation Assay

Each pot was filled with 1.5 kg of processed paddy soil and amended with the corresponding CCB treatment. The soil and biochar were thoroughly mixed to ensure uniform dispersion. Sterile distilled water (25 mL) was added twice weekly to maintain optimal moisture levels, as recommended by Nkereuwem *et al.* (2021) and Abioye *et al.* (2012). The pots were incubated in a controlled environment for 30 days under ambient temperature (27 – 30 °C) and light conditions. The rice variety Oryza sativa L. (FARO 44), known for its adaptability to local climatic conditions, was cultivated in each pot. This variety was selected based on its agricultural relevance and availability in the study area.

2.6. Monitoring and Analysis

During the 30-day incubation period, treatments were monitored for moisture retention and any visible changes in soil structure. Final evaluations included a detailed analysis of physicochemical and microbial properties, focusing on biochar-soil interactions as highlighted by Abass *et al.* (2021) and Lehmann & Joseph (2015).

2.7. Data Analysis

Microsoft Excel 2013® (Microsoft Corporation, USA) and Statistics 8.1® (Analytical Software, USA) were used to analyze the data. One-way ANOVA was performed on the pot experiment data, and the mean findings were compared using Tukey's multiple comparison test, with a significance level of $p < 0.05$.

3. Results and Discussion

3.1. Characterization of Paddy Soil and Corncob-Biochar

The physical and chemical characteristics of the paddy soil and corncob-biochar (CCB) used in the study are detailed in Table 1. The paddy soil texture was classified as loamy sandy, with sand constituting 71.9 %, silt 15.14 %, and clay 12.64 %. The initial soil pH was mildly acidic (1.3), while the biochar displayed a pH of 5.10, indicating its alkaline nature. The electrical conductivity (EC) of biochar was significantly higher (0.98 µS/cm) than that of the soil (0.07 µS/cm). This disparity aligns with the findings of Nkereuwem *et al.* (2021), who reported that biochar improves soil nutrient availability but may elevate EC, requiring careful management. The total organic carbon (TOC) and organic matter (OM) content in biochar were markedly higher than in the untreated soil, likely contributing to the increased cation exchange capacity (CEC) observed in biochar (36.40 mol/kg) compared to soil (7.20 mol/kg). These properties are consistent with the role of biochar in enhancing soil fertility by increasing organic carbon availability and CEC (Tesfahun, 2018).

Table 1. Characteristics of the corncob biochar (CCB) and paddy soil (PS) utilized in the study

Parameters	**Units**	**Soil**	**CCB (Values at 300 °C)**
Sand	%	71.90	-
Silt	%	15.14	-
Clay	%	12.64	-
Textural Class		Loamy Sandy	-
pH (H_2O)		1.3	5.10
Av. Phosphorous (P)	mg/kg	8.31	5.72
Electrical Conductivity (EC)	µS/cm	0.07	0.98
Exchange Acidity (EA)	mol/kg	0.33	0.87
Cation Exchange Capacity (CEC)	mol/kg	7.20	36.40
Popotassium (K)	mol/kg	-	0.11
Organic Carbon (OC)	g/kg/%	-	0.71
Organic Matter (OM)	cmol/%	-	1.22

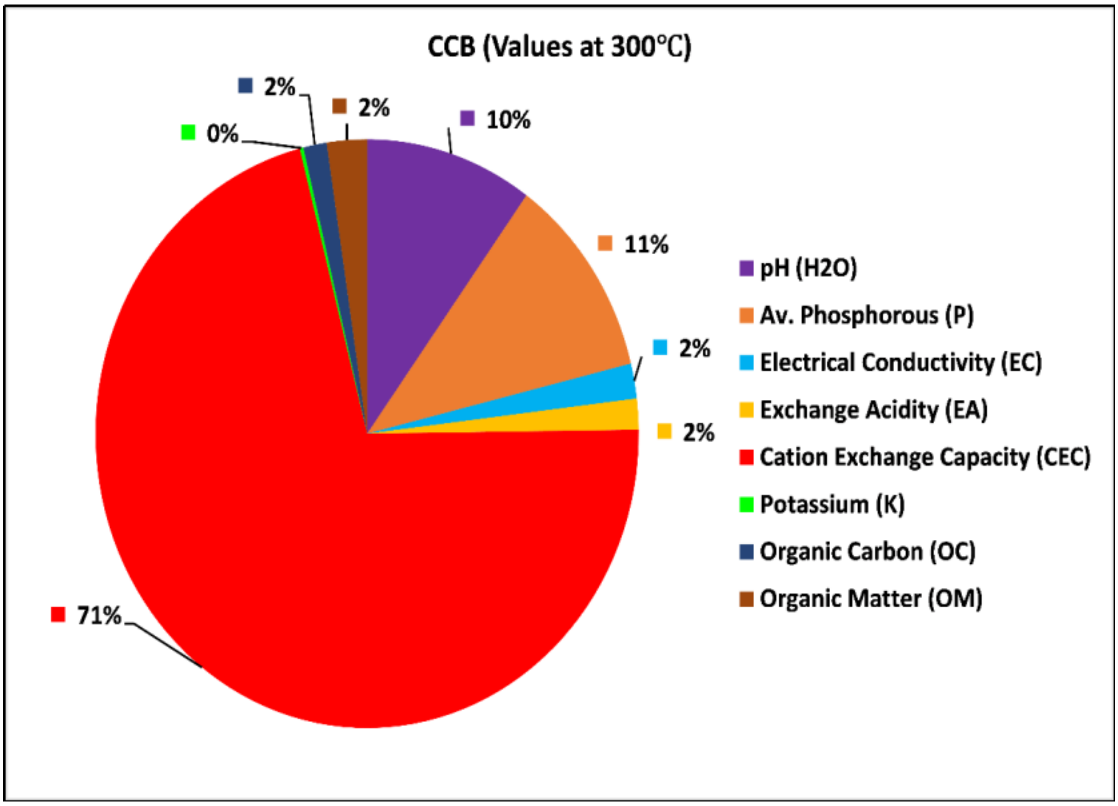

Figure 1. Percentage of the exchange acidity, available phosphorus, CEC, potassium, carbon from organic sources, and soil organic matter from the polluted paddy soil both before and after biochar treatment.

3.2. Effects of Corncob Biochar (CCB) Addition on Soil Composition

3.2.1. pH

The results in Table 2 demonstrate that biochar significantly increased the soil pH across all treatment levels, with values ranging from 8.10 (TP1) to 9.10 (TP4). These findings confirm biochar's alkalinity-enhancing effects, as previously documented by Wang *et al.* (2019). However, the pH in treatments TP3 and TP4 exceeded the acceptable agricultural range of 5.5 – 8.6 (Zhao *et al.*, 2021), potentially inhibiting nutrient availability.

3.2.2. Electrical Conductivity (µS/cm)

Similarly, EC values increased with higher biochar concentrations, ranging from 2.28 µS/cm (TP1) to 3.08 µS/cm (TP4), exceeding the standard maximum limit of 1.8 µS/cm for soil salinity (Mohurd, 2011). High EC values can impede plant growth due to salinity stress, suggesting that excessive biochar application requires mitigation strategies. Potential approaches include diluting biochar with other organic amendments or optimizing application rates to balance soil pH and EC (Tesfahun, 2018).

Table 2. Selected physicochemical characteristics of paddy soil amended with corncob biochar

Parameters	Units	Control	Treatment			
			TP1 (50:100)	**TP2 (50:150)**	**TP3 (100:250)**	**TP4 (300:500)**
pH (H_2O)		1.30	8.10	8.55	8.55	9.10
EC	µS/cm	0.07	2.28	2.45	2.80	3.08
Organic Carbon	g/kg/%	-	1.09	1.09	1.11	1.14
Organic Matter	mol/%	-	1.78	1.88	1.89	1.97
Av. Phosphorous	mg/kg	8.31	15.89	15.90	15.96	16.39
Ex. Acidity	mol/kg	0.33	1.13	1.14	1.13	1.17
CEC	mol/kg	7.20	39.10	40.12	41.17	43.21
Potassium (K)	mol/kg	-	5.24	5.74	6.12	6.78

3.2.3. Exchangeable Acidity and Cation Exchange Capacity (CEC)

The addition of biochar reduced exchangeable acidity (EA) in the treated soils, with TP1 showing the most significant reduction. The reduction aligns with the findings by Amirahmadi *et al.* (2020), who noted that biochar neutralizes acidic soils by transforming exchangeable Al^{3+} into insoluble hydroxyl-Al complexes. Furthermore, the CEC increased substantially with biochar application, from 7.20 mol/kg in untreated soil to 43.21 mol/kg in TP4. Enhanced CEC improves soil nutrient retention, as corroborated by Laird *et al.* (2010), and is critical for supporting plant growth under variable environmental conditions.

3.2.4. Phosphorus and Potassium Availability

Phosphorus availability increased across all treatments, with the highest concentration observed in TP4 (16.39 mg/kg). This aligns with Gao *et al.* (2021), who demonstrated that biochar reduces phosphorus leaching while enhancing its availability for plant uptake. Potassium levels similarly increased, peaking at 6.78 mol/kg in TP4, reflecting biochar's role in nutrient adsorption and release, as noted by Zhu *et al.* (2017).

3.2.5. Organic Carbon and Organic Matter

The organic carbon and organic matter content improved significantly with biochar treatment, ranging from 1.09 g/kg in TP1 to 1.14 g/kg in TP4. Biochar's recalcitrant nature and high carbon stability contribute to these improvements, as documented by Lehmann *et al.* (2011). Increased organic carbon enhances microbial activity and soil structure, fostering long-term soil health.

Conclusions

This study investigated the impact of corncob-derived biochar (CCB) on ameliorating the soil quality of rice farms in Dutse, Nigeria. The findings reveal that the incorporation of CCB significantly improved key soil parameters, including pH, cation exchange capacity (CEC), organic matter, and nutrient availability (phosphorus and potassium). Biochar application enhances soil fertility and nutrient retention, crucial for supporting crop productivity in degraded and nutrient-depleted soils. However, the results also highlight potential limitations. High biochar application rates increased soil electrical conductivity (EC) and pH beyond optimal ranges for plant growth. These observations underscore the need for careful calibration of biochar application rates to prevent potential soil salinity-alkalinity challenges. Overall, the study demonstrates that biochar derived from corncobs is a sustainable amendment for improving soil quality in rice farms, particularly in resource-constrained settings. Its application aligns with climate-resilient agricultural practices by enhancing carbon sequestration and reducing nutrient losses. Based on the findings from this study, it can be recommended that to maximize the benefits of biochar while mitigating potential challenges like excessive EC and pH, application rates should be carefully optimized based on soil type, crop needs, and environmental factors. Blending biochar with other soil amendments can further balance its effects, especially in salinity-prone soils. Long-term monitoring is essential to evaluate biochar's impact on soil quality and microbial interactions. Additionally, educating farmers on biochar production and application will encourage adoption, particularly among smallholders, while policymakers should support these efforts through subsidies, training programs, and integration into sustainable agricultural strategies.

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Conflicts of Interest

We, the authors of this article, solemnly declare that we have no conflict of interest.

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