

Valorization of corncob biochar as a slow-release fertilizer

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ABSTRACT

This study aimed to evaluate the effect of corn cob biochar as a slow-release organic fertilizer on the growth and yield of maize plants and to determine its optimal dosage for achieving this effect. The study used five biochar dosage treatments: 0, 5, 10, 15, and 20 t.ha⁻¹, with three replicates each. The results showed that the application of biochar significantly affected the plant height, leaf number, and stem diameter. The highest dosage (20 tons.ha⁻¹) produced the best values for these parameters. In terms of yield components, biochar had a significant effect on the weight of fresh-peeled cobs, whereas the number of cobs and cob length showed no significant differences among the treatments. Overall, a dose of 20 tons.ha⁻¹ was recommended as the optimum dose under the conditions of this experiment. These findings confirm the potential of corn cob biochar as a sustainable organic fertilizer that can increase maize productivity through gradual nutrient release mechanisms.

Keywords:

Cation exchange capacity, Fertilization efficiency, Nutrients, Pyrolysis, Soil properties

1. Introduction

A sustainable increase in agricultural productivity is one of the main challenges in the development of the current agricultural sector. Amid the rising global demand for food, conventional farming practices that rely on external inputs such as synthetic chemical fertilizers are increasingly under scrutiny because of their negative environmental impacts. Dependence on chemical fertilizers not only leads to declining soil quality due to long-term fertility degradation but also poses threats of groundwater contamination and the accumulation of harmful residues in agricultural products. Therefore, the search for environmentally friendly, efficient, and sustainable fertilizer alternatives has become a strategic issue in the development of modern agricultural systems.

Biochar, a carbon-rich solid produced by the pyrolysis of biomass under limited oxygen, improves soil cation exchange capacity (CEC), water retention, and nutrient availability. It serves a dual role as a soil ameliorant and as a long-term carbon sink. Among the various biomass wastes, corn cobs represent a particularly viable feedstock in regions such as Indonesia, which produces over 20 million tons of corn annually, resulting in vast underutilized cob waste. Corn cob biochar is noted for its favorable porosity and carbon-to-nitrogen (C/N) ratio [1]. Thus, biochar acts not only as a soil ameliorant but also as an important agent for climate change mitigation through long-term carbon storage.

While existing research confirms the potential of biochar to boost crop yields in acidic soils and enhance microbial activity as a slow-release medium, critical gaps remain,



especially in the Indonesian context. Few studies have systematically linked pyrolysis parameters (temperature and residence time) to the physicochemical properties of corn cob biochar and its subsequent agronomic effectiveness in tropical soils. This optimization is crucial because pyrolysis conditions directly determine the carbon content, surface area, and pore structure of biochar, which govern its nutrient and water interaction. Research by Park et al. [2] showed that biochar made from corn cobs possesses high porosity and an ideal carbon-to-nitrogen (C/N) ratio for agricultural applications.

Several studies have evaluated the effects of biochar on soil fertility. For instance, research by Tazebew et al. [3] showed that the application of biochar to acidic tropical soils can increase crop yields by up to 45% compared with that of the control. In addition, Li et al. [4] stated that the use of biochar can enhance soil microbial activity and prolong the release time of nutrients, making it suitable as a slow-release fertilizer. Nevertheless, research specifically examining the optimization of the production process of corn cob-based biochar and a comprehensive characterization of its effectiveness as a slow-release fertilizer in Indonesia's tropical soils is still very limited.

In addition to the literature gap regarding the physicochemical characterization of corn cob biochar, few studies have directly linked pyrolysis process parameters (such as temperature and residence time) to biochar quality in the context of fertilization efficiency and empirical plant growth outcomes. This is important because the final characteristics of biochar are greatly influenced by pyrolysis conditions. The pyrolysis temperature affects the carbon content, specific surface area, and pore structure of biochar, which directly play a role in the interaction of biochar with nutrients and water in the soil [5-8].

This research is relevant considering the urgent need for sustainable fertilization solutions, especially for smallholder farmers who face limited access to chemical fertilizers owing to price fluctuations and distribution challenges. By developing corn cob waste processing technology into biochar as a slow-release fertilizer, this study aims to provide local solutions to global issues. The use of biochar also aligns with the principles of regenerative agriculture and circular economy-based waste management, which are currently the central paradigms of sustainable agricultural development.

The novelty of this research lies in the integrative approach between optimizing the production process of corn cob-based biochar, in-depth physicochemical characterization, and testing the effectiveness of biochar in different tropical soil contexts. In addition to focusing on biochar production, this study also covers empirical testing through application in agricultural soils to measure its impact on water retention, nutrient availability, and plant growth under real-world conditions. This approach provides both scientific and practical contributions to the development of alternative fertilizers that are affordable, accessible, and environmentally friendly in the future.

Based on the background and literature review above, the objective of this study is to develop a technology for processing corn cob waste into an effective biochar as a slow-release fertilizer that supports sustainable agriculture. Specifically, this study aimed to optimize pyrolysis parameters in the production of biochar from corn cobs

and evaluate the effectiveness of biochar in improving soil properties and plant growth through field application tests with a controlled experimental design.

2. Methods

This research was conducted at two main locations: the experimental plot owned by the Bunga Jagung Women Farmers Group (Kelompok Wanita Tani, KWT) located in Galung Maloang Village, Bacukiki District, Parepare City (Figure 1). The research was conducted over four months, from July to October 2025, covering all stages from biochar production, field testing, to the analysis of harvest data.



Figure 1. Research location

The main raw material used was dried corn cob waste, which was obtained from local farmers. For agronomic testing, soil from the experimental site and seeds of a local corn variety were used. This study followed an integrated workflow beginning with biochar synthesis and proceeding to field evaluation. The first stage was the preparation and Characterization of biochar. Corn cobs were pyrolyzed in a batch reactor under limited oxygen conditions. To optimize the process, key parameters were varied: temperature at 300, 400, 500, and 600 °C, and residence time at 30, 60, and 90 min. This matrix enabled the investigation of the influence of these parameters on the the critical biochar properties of the resulting biochar. High temperatures (e.g. Temperatures of 500–600 °C) generally enhance porosity and surface area, whereas lower temperatures (300–400 °C) tend to preserve a higher volatile matter content. The resulting biochar were characterized in terms of yield, pH, CEC, specific surface area, pore structure, and elemental composition to identify the optimal material for agronomic testing [5]. The third stage was Data Collection, which involved periodic monitoring of plant growth metrics (plant height, leaf area, biomass, and final yield). The collected data were analyzed using Analysis of Variance (Anova) and post-hoc tests using Least Significant Difference (LSD) test at a 5% significance level to determine the effects of treatments on soil properties and plant growth, and to evaluate the effectiveness of biochar as a slow-release fertilizer.

The next stage involved testing the effectiveness of biochar in agricultural land using a randomized complete block design (RCBD) experimental design. The factor tested was the biochar application rate, with five treatments: P0 as the control (no biochar), P1 = 5 t.ha⁻¹, P2 = 10 t.ha⁻¹, P3 = 15 t.ha⁻¹, and P4 = 20 t.ha⁻¹, each with three replicates. Biochar was mixed with the soil according to the treatment dosage and incubated for two weeks before planting the test crop. The parameters observed in this experiment

included plant growth and yield parameters (plant height, number of leaves, dry weight, and yield in tons.ha⁻¹) [6].

Observations were conducted periodically every two weeks for soil parameters and weekly for plant growth parameters until the harvest. Data obtained from these observations were analyzed using Anova to determine the effect of biochar dosage on each variable. If the analysis results indicated significant differences, further tests were conducted using LSD at a 5% significance level. Data processing was carried out with the aid of statistical software, such as SPSS, to enhance the accuracy and reliability of the results.

The methods used in this study were designed to produce comprehensive and valid information on the effectiveness of corn cob biochar as a slow-release fertilizer. By integrating the stages of production, characterization, and effectiveness testing into a single systematic workflow, this study is expected to provide new contributions to the field of sustainable agricultural technology, particularly in relation to the utilization of agricultural biomass waste. This approach is interdisciplinary, combining principles of soil science, environmental chemistry, and agronomy, and considers practical aspects at the farmer level and environmental sustainability.

3. Results and Discussion

The results of the experiment showed the effect of applying corn cob biochar on several growth parameters of corn plants (plant height, number of leaves, stem diameter, and wet ear weight), while some other parameters (number of ears and ear length) did not show significant differences between the treatments. The average plant height and variance analysis indicated that the biochar treatment had a highly significant effect on corn plant height (Table 1).

Table 1. Average plant height in biochar treatment

Doses Biochar	Average Plant Height (cm)	LSD 0.05
P0	69.23 ^b	4.815
P1	72.38 ^b	
P2	76.53 ^{ab}	
P3	76.51 ^{ab}	
P4	79.33 ^a	

Note: Numbers followed by different letters in the column indicate a significant difference at the 0.05 least significant difference (LSD) level.

The results of the LSD test in Table 1 show that the P4 biochar dosage produced the highest average plant height (79.33 cm), which was significantly different from those of P0 and P1. The average plant heights in each treatment were P0 (control) = 69.23 cm, P1 = 72.38 cm, P2 = 76.53 cm, P3 = 76.51 cm, and P4 = 79.33 cm, respectively. Analysis of variance showed that the biochar treatment had a highly significant effect on plant height (treatment F calculated = 7.27, indicating significance at the 1% level). Therefore, post-hoc pairwise comparisons were performed using the Least Significant Difference (LSD) test at the 5% significance level to identify differences between individual treatment means. The follow-up LSD test ($\alpha = 0.05$) showed a significant difference between P4 and P0 and P1, so the highest dosage (P4) resulted in the best average plant height [9].

The average leaf number and analysis of variance showed that the biochar treatment had a highly significant effect on the number of maize leaves.

Table 2. Average number of leaves in biochar treatments

Doses Biochart	Average Number of Leaves (cm)	LSD 0.05
P0	7.17 ^c	0.679
P1	7.92 ^b	
P2	8.42 ^b	
P3	9.33 ^a	
P4	9.92 ^a	

Notes: Numbers followed by different letters in the column indicate a significant difference at the 0.05 level in the LSD test.

The results of the LSD test in Table 2 show that the P4 biochar dose produced the highest average number of plant leaves at 9.92 cm, which differed significantly from the P0, P1, and P2 treatments. The average number of leaves increased with increasing biochar dose: P0 = 7.17, P1 = 7.92, P2 = 8.42, P3 = 9.33, and P4 = 9.92. The analysis of variance showed a highly significant effect (calculated $F = 27.95$; significant at the 1% level), and the LSD test confirmed that P4 was significantly different from P0, P1, and P2. The increase in the number of leaves at higher doses indicates stimulated vegetative growth, which is consistent with the hypothesis that biochar improves water availability and nutrient retention, thereby extending the leaf assimilation phase of plants. These results are consistent with previous findings that reported an increase in vegetative biomass after biochar application [10].

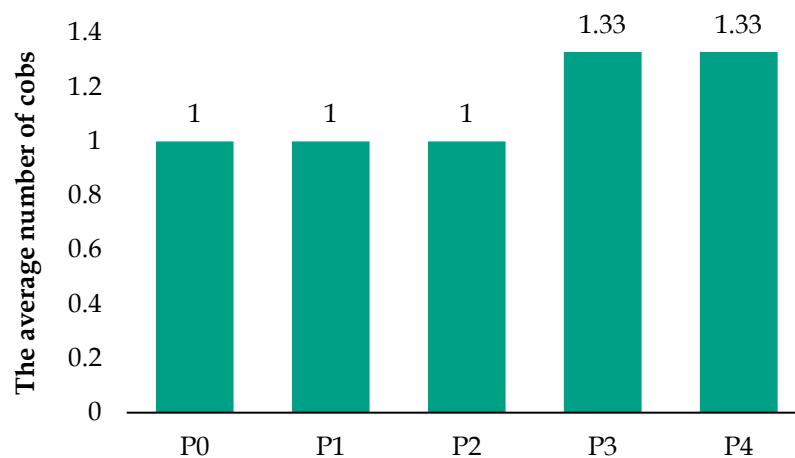


Figure 2. The average number of cobs at various biochar doses. P0 = Control, P1 = 5 ton.ha⁻¹, P2 = 10 ton.ha⁻¹, P3 = 15 ton.ha⁻¹, P4 = 20 ton.ha⁻¹

Figure 2 shows that the greatest number of cobs was recorded at the P3 and P4 biochar doses, at 1.33, while the lowest number of cobs was found at P0, P1, and P2, at 1.00 cobs per plant. The average number of cobs was relatively constant (averaging approximately 1.00–1.33). The summary figure shows the highest number of cobs at P3 and P4 (1.33) and the lowest at P0–P2 (1.00). This lack of significance indicates that, under these experimental conditions, biochar application has a stronger effect on vegetative components than on the number of reproductive organs (number of cobs), which may be affected by other factors such as varietal genetics, plant population, or

environmental conditions during cob formation [11]. Analysis of variance showed that the biochar treatment had no significant effect on maize cob number.

The average stem diameter and variance analysis indicated that the biochar treatment had a highly significant effect on the maize stem diameter.

Table 3. Average stem diameter under biochar treatments

Doses Biochart	Average Stem Diameter (cm)	LSD 0.05
P0	1.51 ^d	0.137
P1	1.68 ^c	
P2	1.86 ^b	
P3	1.98 ^b	
P4	2.15 ^a	

Notes: Numbers followed by different letters in the column indicate a significant difference at the 0.05 LSD test level

The results of the LSD test in Table 3 indicate that the P4 biochar dose yielded the largest average stem diameter at 2.15 cm, which differed significantly from the P0, P1, P2, and P3 treatments. The average stem diameter increased significantly with biochar amendment: P0 = 1.51 cm, P1 = 1.68 cm, P2 = 1.86 cm, P3 = 1.98 cm, and P4 = 2.15 cm. Anova showed a highly significant effect (calculated F treatment = 34.58; significant at 1%), and LSD showed that P4 was significantly different from P0-P3. The increase in stem diameter at higher doses indicates a strengthened plant structure, which may be linked to the increased availability of nutrients (e.g. N, K, and Ca) and better water conditions owing to the application of biochar. A larger stem diameter also has implications for plant resistance to mechanical stress and the potential flow of assimilates to the cobs [12].

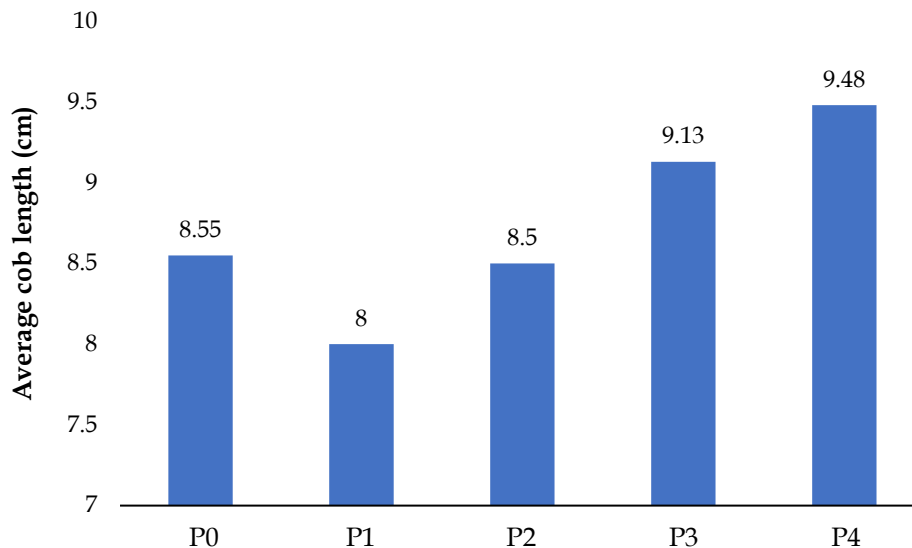


Figure 3. Average cob length at various biochar doses. P0 = Control, P1 = 5 ton.ha⁻¹, P2 = 10 ton.ha⁻¹, P3 = 15 ton.ha⁻¹, P4 = 20 ton.ha⁻¹

Figure 3 shows that the longest cob length occurred at the P4 biochar dose (9.48), whereas the shortest occurred at P1 (8.00). The average cob length showed numerical differences (longest at P4 = 9.48 cm, shortest at P1 = 8.00 cm), but Anova indicated no

significant difference among treatments. This suggests that, although there is a tendency for increased cob length at higher doses, the current data variability and sample/replication sizes are insufficient to indicate a significant effect on cob length. Other factors (e.g. sink-source relationships and pollination conditions) may influence cob length; therefore, the effect of biochar on this variable is less clear in this experiment [13]. The average cob length and variance analysis showed that the biochar treatment had no significant effect on the maize cob length.

The average fresh unskinned cob weight and variance analysis showed that the biochar treatment had a highly significant effect on the fresh unskinned cob weight.

Table 4. Average fresh unskinned cob weight under biochar treatments

Doses Biochar	Average Fresh Unskinned Cob Weight (g)	LSD 0.05
P0	32.50 ^b	22,13
P1	42.67 ^{ab}	
P2	42.00 ^{ab}	
P3	41.67 ^{ab}	
P4	55.00 ^a	

Notes: Numbers followed by different letters in the column indicate a significant difference at the 0.05 level of the LSD test.

The results of the LSD test in Table 4 show that the P4 biochar dose produced the heaviest average fresh unskinned cob weight at 55.00 g, which was significantly different from that of P0. The average fresh unskinned cob weight increased clearly at the highest dose: P0 = 32.50 g, P1 = 42.67 g, P2 = 42.00 g, P3 = 41.67 g, and P4 = 55.00 g. Anova showed a highly significant effect (calculated F treatment = 11.15; significant at 1%), and LSD indicated that P4 differed significantly from P0. This increase in cob weight is an indicator of improved commercial yield (yield per cob), most likely due to improved water and nutrient availability and slower nutrient release (“slow-release” effect) when biochar is added to the soil. These results support the assumption that corn cob biochar has the potential to improve yields through mechanisms that improve soil properties and reduce nutrient loss (2).

In general, the observed pattern of positive responses in vegetative parameters, specifically plant height, leaf count, and stem diameter, was consistent with the established literature. Previous studies [14,15] have indicated that biochar can enhance soil water retention, cation exchange capacity (CEC), and nutrient availability over the medium term, which subsequently improves plant growth. The porous structure of biochar is also known to improve soil microbial habitats, thereby supporting biological processes that increase nitrogen (N) and phosphorus (P) availability. However, it should be noted that this study did not directly measure soil microbial activity, CEC, or specific nutrient dynamics; therefore, the mechanistic explanations above are interpretations based on the existing literature rather than direct evidence from the dataset. Variations in response levels across parameters (e.g. the non-significant effect on the number of ears) have also been reported in other studies. The literature suggests that the effects of biochar are often more pronounced on soil properties and vegetative growth than on direct reproductive yield components, unless it is combined with optimized nutrient inputs or complementary agronomic management. This aligns with the findings of the present study, where

vegetative metrics showed clearer improvement than the final ear count. The strengths of this study include the integration of a controlled pyrolysis optimization process with subsequent field validation under local tropical conditions, providing a direct link between biochar production parameters and agronomic performance [16–18].

The use of only three replicates ($n=3$) reduced the statistical power of the analysis. This increases the likelihood of a Type II error (failing to detect a real effect), which likely explains why some treatment effects, particularly for more variable parameters such as ear count, did not reach statistical significance. A key mechanistic gap in this study is the lack of quantitative data on soil property changes (e.g. pH, CEC, and available NPK) after biochar application. Although the observed plant growth responses are consistent with the known soil-amending properties of biochar, the absence of direct evidence weakens the causal link between application and response. Therefore, our discussion of mechanisms (e.g. improved nutrient availability and water retention) remains a literature-supported interpretation rather than a conclusion verified by our dataset. The two-week incubation period prior to planting may have been insufficient for complete biochar-soil interaction to occur. The effects of biochar on cation exchange and nutrient cycling often develop over months. Consequently, this study primarily captures the initial, short-term agronomic response and cannot inform the longer-term soil fertility benefits or carbon sequestration potential of the applied biochar.

From these results, the P4 dose (20 tons.ha⁻¹) provided the best growth response and ear weight among the tested treatments and is therefore recommended as a promising initial dose for further field-scale evaluations. However, it is important to emphasize that this suggested rate represents the best-performing option within the specific conditions and limited range of this study and is not necessarily the true economic or agronomic optimum rate. Consequently, it is strongly recommended that this dose be validated under broader field conditions, across different soil types and seasons, and in combination with optimized mineral fertilizer inputs to develop a balanced and cost-effective integrated nutrient management strategy, but it should be re-tested on a larger field scale and in combination with controlled mineral fertilization strategies to determine the economically optimal combination [4,19,20].

4. Conclusion

Based on the experimental results, the application of corn cob biochar significantly influenced several corn growth parameters. Increasing biochar doses were associated with improved vegetative growth, specifically plant height, leaf count, and stem diameter. This observed growth enhancement is consistent with literature reports that biochar can improve the soil's physical and chemical properties, such as water retention and nutrient availability, although these specific mechanisms were not directly measured in this study. Biochar application had a significant effect on wet peeled ear weight. However, no significant differences were detected in the number or length of ears, indicating a variable effect on different yield components. Among the tested doses, the highest application rate of 20 tons.ha⁻¹ (P4) resulted in the most favorable growth and yield responses under the conditions of this trial. Therefore, this dose can be proposed as a promising starting point for further large-scale evaluations. Overall, this study provides evidence that corn cob biochar has the

potential to be used as a sustainable soil amendment. These effects align with the conceptual framework of a slow-release nutrient source, contributing to increased maize productivity within the experimental context. Further research incorporating direct soil property analysis and long-term field trials is recommended to confirm the underlying mechanisms and economic viability.

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