Research Paper

Coconut Shell Biochar and Sheep Manure for Food Security of Maize on Samas Coastal Sandy Land

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Abstract

Coastal sandy soils have limited productivity due to their low organic matter content, cation exchange capacity, and water-holding ability, thus requiring environmentally friendly soil management innovations. Coconut shell biochar is known to improve soil physico-chemical properties, while sheep manure serves as a source of readily mineralizable organic nutrients. However, the interaction between the two in maize cultivation systems on coastal sandy soils has not been extensively studied. This study aimed to evaluate the effects of combined doses of coconut shell biochar and sheep manure on soil chemical properties and maize productivity in the sandy soils of Samas Coast. The research employed a Randomized Block Design (RBD) with two factors: biochar dose (0, 10, 15, and 20 tons/ha) and sheep manure dose (0; 2,5; 5; and 7,5 tons/ha). Observed parameters included soil organic C, cation exchange capacity (CEC), plant dry weight, and maize yield (tons/ha). Data were analyzed using analysis of variance (ANOVA), followed by post-hoc tests to determine differences among treatments. The results showed that the addition of biochar and sheep manure had significant effects on all observed parameters. The combination of medium biochar dose (20 tons/ha) and high sheep manure dose (30 tons/ha) (B2K3) resulted in the highest increase in CEC (28.5 me%), organic C (1.25%), plant dry weight, and maize yield exceeding 10 tons/ha. This indicates a synergistic effect between biochar and sheep manure in improving soil fertility and maize productivity on sandy soils. These findings contribute to the development of sustainable coastal soil management strategies, reducing dependence on chemical fertilizers and thereby supporting food security.

Keywords *Soil Ameliorant, Biochar, Sheep Manure, Coastal Sandy Land, Coconut Shell*

INTRODUCTION

Coastal sandy soils are one of the marginal ecosystems that face significant limitations in agricultural productivity. The main characteristics of sandy soils are their low cation exchange capacity (CEC), low organic matter content, and poor water-holding capacity, which restrict the availability of essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K). These conditions hinder the optimal productivity of food crops, including maize (*Zea mays L.*), without the application of appropriate soil management technologies. Therefore, efforts to improve soil fertility are crucial for supporting food security in coastal areas, such as Samas Beach, Yogyakarta.

One of the soil amelioration technologies that has been widely studied is the application of biochar. Coconut shell biochar functions as a soil conditioner with the ability to improve soil structure, increase porosity, and enhance the soil's capacity to retain water and nutrients. Additionally, biochar serves as a habitat for soil microorganisms, which play a crucial role in nutrient mineralization and availability. Previous studies have shown that biochar not only promotes root development but also improves nutrient uptake efficiency in sustainable agricultural

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systems (Herlambang et al., 2025a).

The effectiveness of biochar application can be further enhanced when combined with other sources of organic nutrients, such as sheep manure. Sheep manure is an organic material rich in macronutrients, particularly nitrogen and phosphorus, which complements the physical functions of biochar in improving soil nutrient availability. The combination of biochar and sheep manure has been proven to increase the availability of N, P, and K in soils and improve the growth of both horticultural and food crops (Putri & Herlambang, 2025). In the context of food security, the synergy between coconut shell biochar and sheep manure represents a promising strategy to enhance maize productivity on coastal sandy soils.

Thus, this study aims to examine the effects of coconut shell biochar combined with sheep manure on the growth and food security potential of maize in the sandy soils of Samas Beach. The findings are expected to provide a tangible contribution to the sustainable management of marginal lands and to support national food security efforts.

LITERATURE REVIEW

The primary issue with Samas' coastal sandy soils is their low fertility, resulting from an extremely low organic matter content, a coarse sand texture with large pores that facilitate nutrient leaching, and a limited water-holding capacity. These conditions directly lead to low maize productivity, despite maize being one of the country's strategic food crops. Efforts to improve productivity using inorganic fertilizers are often inefficient due to high nutrient losses through leaching. Therefore, alternative land management practices are required to improve the physical, chemical, and biological properties of the soil in an integrated manner. Coconut shell biochar has the potential to act as a soil ameliorant by enhancing nutrient retention capacity, while sheep manure provides a valuable source of organic nutrients. The combination of both is expected to increase nutrient availability and support maize-based food security in the sandy soils of Samas Beach.

Coastal sandy soils fall under the category of marginal lands with low productivity caused by limitations in their physical and chemical properties. Their coarse texture results in low cation exchange capacity (CEC) and poor water-holding ability, leading to rapid nutrient leaching and limited nutrient availability for plants over time. These conditions make coastal sandy soils less suitable for the production of strategic food crops, such as maize, without the application of appropriate technological inputs (Herlambang & Sutiono, 2019). Therefore, amelioration strategies are necessary to enhance soil structure, increase nutrient availability, and promote crop growth.

Biochar is a product of biomass pyrolysis at high temperatures under limited or no oxygen. Coconut shell biochar exhibits high porosity, a large surface area, and stable carbon content, which collectively contribute to enhancing soil quality. Its application has been proven to enhance the soil's capacity to retain water and nutrients, improve soil aggregation, and provide a habitat for beneficial soil microorganisms (Herlambang & Sutiono, 2019; Herlambang et al., 2022). Furthermore, biochar functions as a slow-release fertilizer, holding nutrients and gradually releasing them for more efficient plant uptake (Putri & Herlambang, 2025).

Sheep manure, on the other hand, is an organic material rich in macronutrients, particularly nitrogen (N), phosphorus (P), and potassium (K). Its nutrient content improves soil fertility and supports the growth of food crops. The application of sheep manure also stimulates soil microbial activity, accelerates decomposition, and provides an energy source for microbes involved in nutrient mineralization (Herlambang et al., 2025b). In sustainable farming systems, sheep manure acts not only as an organic fertilizer that supplies essential nutrients but also as a source of organic carbon to enhance soil quality.

The combined application of biochar and sheep manure produces a synergistic effect on improving soil fertility. Biochar enhances the soil's physical properties and nutrient retention, while sheep manure supplies readily available nutrients for crop growth. Together, they have been shown to increase the availability of N, P, and K, promote root system development, and improve the productivity of food crops (Herlambang et al., 2025a; Putri & Herlambang, 2025). This synergy makes coconut shell biochar and sheep manure a promising strategy for improving maize productivity in marginal lands, such as the Samas coastal sands, while simultaneously contributing to sustainable food security.

Recent evidence indicates that the agronomic effectiveness of biochar is strongly context-dependent, with outcomes influenced by soil pH, application rates, and local site conditions (Ibrahimi & Alghamdi, 2022). In sandy soils, biochar has been shown to improve nutrient cycling, water retention, and soil structure, with reported increases of over 20% in both field capacity and available water (Wei et al., 2023). Long-term trials in tropical sandy soils further demonstrated sustained improvements in cation exchange capacity, available phosphorus, exchangeable potassium, and aggregate stability (Prakongkep et al., 2020). Moreover, biochar enhances microbial diversity, including beneficial stress-tolerant microbes that support soil fertility (Azeem et al., 2023). Notably, the integration of biochar with organic amendments such as manure has yielded the most significant benefits, with substantial gains in crop yield, soil organic carbon, and soil moisture (Musei et al., 2024). These findings highlight the potential of combining biochar with nutrient-rich organic inputs as a promising strategy for restoring fertility in marginal coastal soils.

RESEARCH METHOD

This study employed a Randomized Block Design (RBD) with two treatment factors, namely coconut shell biochar and solid sheep manure. The RBD was chosen to account for the environmental heterogeneity typical of coastal sandy soils, where blocking helps control spatial variation and ensures more reliable comparisons among treatments (Ajien et al., 2022). The RBD method was applied to determine the interaction between biochar and sheep manure on maize productivity, soil organic carbon content, and cation exchange capacity (CEC). Each experimental plot measured 3 × 3 meters, with a total of 48 experimental units. The treatment combinations of solid sheep manure and coconut shell biochar were as follows:

B0: Coconut shell biochar at a dose of 0 ton/ha
B1: Coconut shell biochar at a dose of 10 tons/ha
B2: Coconut shell biochar at a dose of 15 tons/ha
B3: Coconut shell biochar at a dose of 20 tons/ha
K0: Sheep manure at a dose of 0 ton/ha
K1: Sheep manure at a dose of 2.5 tons/ha
K2: Sheep manure at a dose of 5 tons/ha
K3: Sheep manure at a dose of 7.5 tons/ha

Data were analyzed using analysis of variance (ANOVA) at a 5% significance level. If significant differences were observed, further testing was carried out using Duncan's Multiple Range Test (DMRT) at the 5% level, with the aid of SAS (Statistical Analysis System) software. The parameters measured included plant dry weight, yield, soil organic carbon content, and cation exchange capacity (CEC). The research stages included a preliminary survey to determine the study location suitable for maize cultivation on coastal sandy soils, followed by soil sampling using a descriptive method according to predetermined procedures.

FINDINGS AND DISCUSSION

Coastal lands dominated by sand fractions require specific management practices to improve agricultural productivity in coastal areas. The application of nutrient sources such as sheep manure and soil ameliorants in the form of biochar is expected to maintain soil nutrient availability, thereby enhancing nutrient uptake by maize plants and ultimately increasing crop yields. Additionally, incorporating coconut shell biochar and sheep manure has the potential to reduce dependence on chemical fertilizers, thereby preventing their excessive use. The discussion in this study focuses on several key parameters that reflect plant responses and soil quality in relation to the application of coconut shell biochar and sheep manure, namely plant dry weight, yield, soil organic carbon content, and cation exchange capacity (CEC). These four parameters were selected because they are interrelated in describing the effectiveness of organic inputs and ameliorants in improving soil fertility and crop productivity.

A. Dry Weight

The study's results on the average number of tillers in maize plants after treatment showed that the combination of biochar and sheep manure doses influenced the increase in average dry weight, as presented in Figure 1.

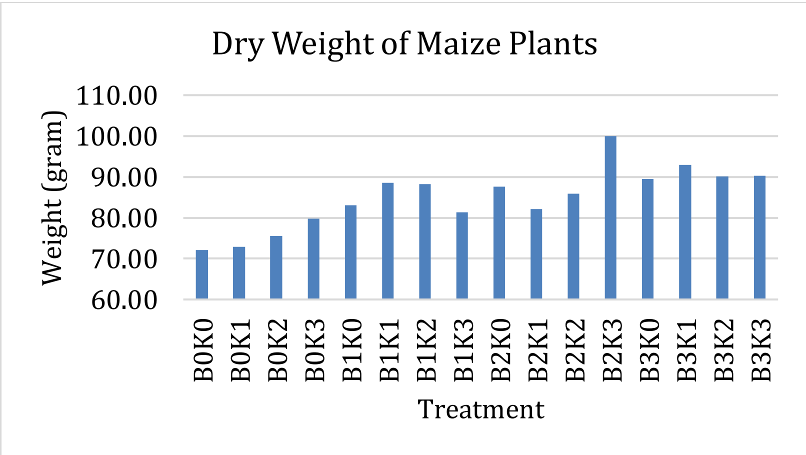

Figure 1. Average Dry Weight of Maize Plants with Biochar and Sheep Manure Treatments

The graph illustrates the variation in the effects of biochar (B) and sheep manure (K) doses on the observed parameter. In general, there is an increasing trend in values along with higher doses of both biochar and sheep manure, although the patterns of increase vary across treatment combinations. In the treatment without biochar (B0), the increase in sheep manure doses (K0–K3) shows a tendency of rising values, from about 72 at B0K0 to nearly 80 at B0K3. This confirms that sheep manure plays an important role as a source of organic nutrients, particularly nitrogen, phosphorus, and potassium, which directly enhance nutrient availability for plants.

At the low biochar dose (B1), combinations with sheep manure (K1–K3) resulted in a more pronounced increase, with the highest values observed at B1K2 and B1K3, approaching 90. This suggests that the presence of biochar begins to exert positive effects on improving plant dry weight, indicating that the addition of both inputs has a beneficial impact on soil nutrient availability.

Furthermore, the medium biochar dose (B2) showed more significant variation. The B2K3 combination reached the highest value, around 100, reflecting a synergistic effect between biochar and sheep manure. Biochar enhances soil capacity to retain nutrients and water, while sheep manure provides readily mineralizable organic nutrients, thereby supporting optimal nutrient uptake by plants. Meanwhile, at the high biochar dose (B3), the resulting values were relatively stable, ranging from 90 to 93, without showing as much increase as in the B2K3 treatment. This suggests that excessive biochar application does not always provide better effects, possibly due to pore saturation or partial immobilization of nutrients. Overall, the results of this study demonstrate that the combination of biochar and sheep manure has a synergistic effect in improving plant growth parameters. The optimal treatment was obtained with the medium biochar dose and high sheep manure dose (B2K3), which provided the highest effectiveness in enhancing nutrient availability while supporting plant productivity.

B. Production

The study's results on the average maize yield after treatment showed that the combination of biochar and sheep manure doses had a significant effect on increasing production. The average yields are presented in Figure 2.

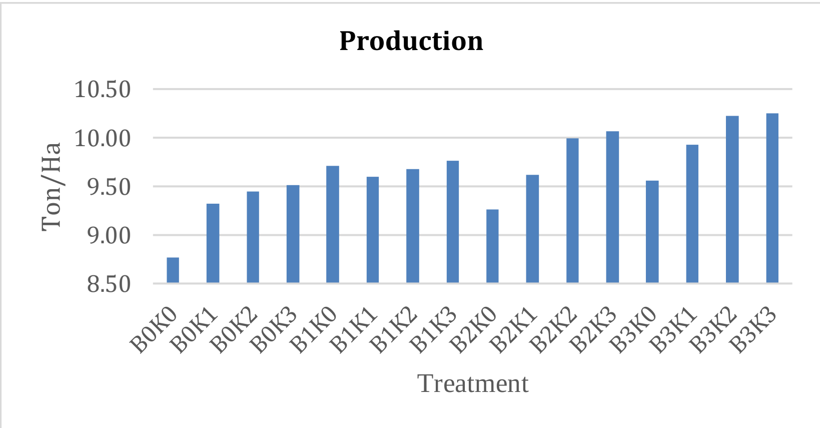

Figure 2. Yield of Maize with Biochar and Sheep Manure Treatments

The yield graph indicates that the combination of biochar and sheep manure treatments had a significant impact on maize production, measured in tons per hectare. In the treatment without biochar (B0), it was observed that increasing sheep manure doses (K0–K3) raised the yield, from about 8.7 t/ha at B0K0 to nearly 9.5 t/ha at B0K3. This demonstrates the role of sheep manure as a primary source of organic nutrients that can improve crop growth and yield. However, yields in the group without biochar were still relatively lower compared to treatments with biochar.

When biochar was added at a low dose (B1), the combination with sheep manure began to show better results, with yields reaching around 9.6–9.7 t/ha. This increase suggests that biochar has contributed to improving soil conditions, particularly in coastal sandy soils that are nutrient-poor and prone to leaching, thereby allowing the organic fertilizer from sheep manure to be utilized more efficiently by plants. At the medium biochar dose (B2), yields further increased, especially in the B2K3 combination, which reached nearly 10 t/ha. This condition indicates a strong synergy between biochar and sheep manure, where biochar enhances nutrient and moisture retention in the soil, while sheep manure provides essential nutrients required by the plants.

Meanwhile, at the high biochar dose (B3), maize yields remained high, ranging from 9.9 to 10.4 t/ha, particularly in the B3K3 combination, which had the highest yield. However, the increase from B2K3 to B3K3 was not substantial, suggesting that excessive biochar application does not always result in proportional yield increases, possibly due to saturation effects or partial nutrient immobilization. Overall, these results indicate that the use of coconut shell biochar combined with sheep manure has a positive effect on increasing maize yields in coastal sandy soils. The best treatments were obtained from medium to high biochar doses combined with high sheep manure doses, where improved nutrient availability and soil conditions enhanced nutrient uptake and increased yields.

C. C-Organic

Soil organic C content is one of the key indicators in assessing soil fertility quality because it plays a vital role in improving the physical, chemical, and biological properties of the soil. Soils with low organic matter content generally have limited capacity to retain water and nutrients; therefore, efforts are needed to enhance it through the application of soil amendments. Biochar, as a source of stable carbon, and sheep manure, as a source of fresh organic matter, represent a potential combination to sustainably increase soil organic C content. The following graph illustrates the effect of the interaction between various doses of biochar (B) and sheep manure (K) on soil organic C content under different treatments. The results of the study on soil organic C content after treatment showed that the combination of biochar and sheep manure doses significantly increased soil organic C levels. The average measurements of soil organic C content are presented in Figure 3.

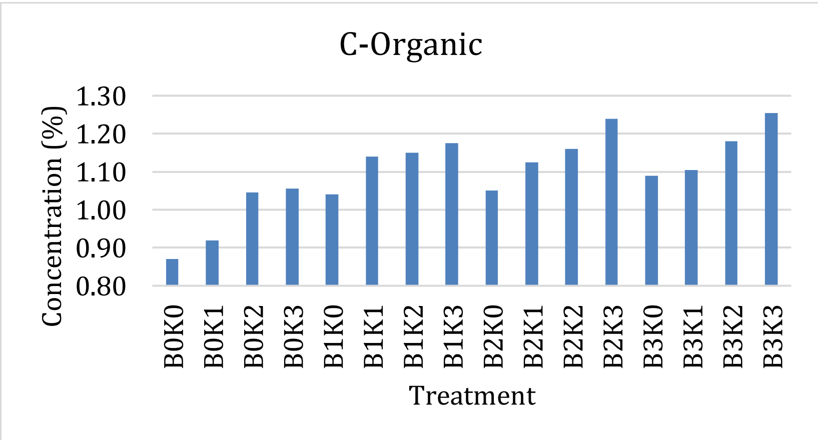

Figure 3. Soil Organic C Content under Biochar and Sheep Manure Treatments

The graph shows that the combined application of biochar (B) and sheep manure (K) generally increased soil organic C content compared to the control (B0K0). In the B0K0 treatment, the lowest organic C level was recorded at approximately 0.85%, reflecting the initial condition of the soil, which was poor in organic matter. An increase in organic C content was observed, reaching around ±1.05% in B0K2 and B0K3. This indicates that sheep manure serves as a direct source of organic matter, contributing to the soil carbon pool. The increase was relatively linear with the applied dosage, consistent with the role of organic fertilizers in improving soil organic matter content.

A more significant increase in organic C content was found in the B1K1 to B1K3 treatments, reaching 1.15–1.18%. This demonstrates the synergistic effect between coconut shell biochar and sheep manure, in which biochar, rich in recalcitrant carbon, is able to maintain organic C reserves for a longer period in the soil. The B2K3 treatment resulted in an even higher organic C content (approximately 1.19%), suggesting that a medium dose of biochar combined with a high dose of sheep manure is efficacious in improving soil organic matter quality.

In the B3K0–B3K3 treatments, organic C content increased substantially, especially in B3K3, which reached 1.25%—the highest value in the graph. This indicates that biochar at a high dosage can provide a considerable contribution of stable carbon, even without manure addition (B3K0 was still higher than B0K0). However, the combination with sheep manure provided an additional increase due to the input of fresh organic matter that is more readily decomposable.

Overall, the higher the dose of biochar and sheep manure applied, the higher the soil organic C content. This supports the findings that biochar is persistent in the soil, thereby contributing to long-term carbon storage, while sheep manure functions as a source of fresh organic matter that stimulates microbial activity. The combination of both is highly effective in improving the quality of sandy soils, which are generally poor in organic matter.

D. Cation Exchange Capacity (CEC)

The results of the study on soil Cation Exchange Capacity (CEC) after treatments showed that the combination of biochar briquettes and sheep manure had a significant effect on increasing CEC. The average measurement results of soil CEC are presented in Figure 4.

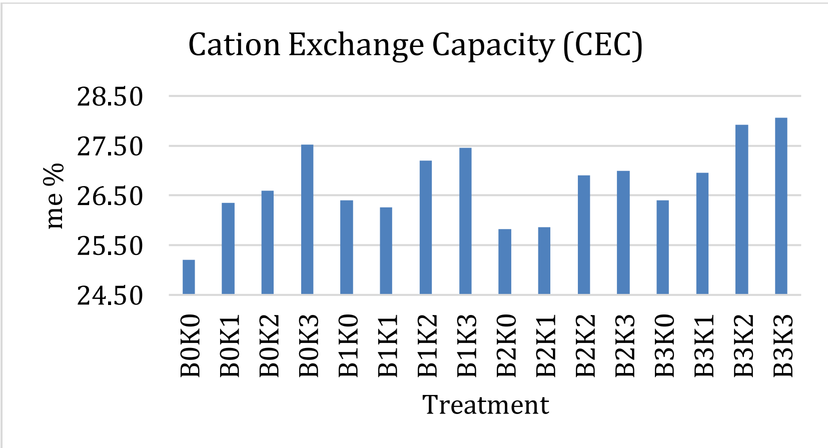

Figure 4. Graph of Soil CEC under Biochar and Sheep Manure Treatments

The graph shows that the application of biochar and sheep manure affected the increase in soil cation exchange capacity (CEC). In the treatment without biochar (B0), CEC values tended to be low, particularly in B0K0, which was only about 25.2 me%, then increased with the addition of sheep manure, reaching 27.5 me% in B0K3. This indicates that sheep manure plays an important role in enhancing soil CEC because it contains organic matter that provides negatively charged functional groups (e.g., carboxyl and phenolic groups), thereby increasing the number of cation exchange sites in the soil.

A more significant increase was observed when biochar was added. At a low dose (B1), the soil CEC increased to approximately 27.4–27.5 me%, especially in the B1K3 combination. This suggests that biochar contributes to improving CEC through its high carbon content and large specific surface area, thus providing more binding sites for nutrient cations such as K^+, Ca^{2+}, Mg^{2+}, and NH_4^+. According to Lehmann and Joseph (2015), biochar has colloidal properties with highly stable negative charges, functioning as a long-term "nutrient reservoir.

Treatments with medium biochar dosage (B2) still showed relatively high CEC values, although not always greater than B1. This may be due to variations in the interaction between biochar and sheep manure in the soil, where some cations from the manure were directly absorbed by plants or leached before binding to the biochar complex. However, compared to the control, B2 treatments still provided significant improvements in soil CEC, highlighting the important role of biochar in maintaining nutrient availability in sandy soils.

The most pronounced increase was observed at the high biochar dosage (B3), particularly in combinations B3K2 and B3K3, which each reached nearly 28.0–28.1 me%. These values were the highest among all treatments. This strengthens the evidence that the combination of high-dose biochar with sheep manure can significantly enhance the soil cation exchange complex, enabling the soil to retain nutrients more effectively and reduce leaching losses. Consequently, nutrient availability for plants can be better maintained, ultimately supporting the increase in maize productivity as shown in the previous yield graph.

CONCLUSIONS

The soil chemical properties (soil organic carbon and cation exchange capacity), as well as the increase in plant dry weight and maize yield in coastal sandy soils, showed significant improvement. The optimal treatment was achieved with medium to high doses of biochar combined with high doses of sheep manure (B2K3 and B3K3), which provided a synergistic effect on nutrient availability and crop productivity. Thus, biochar and sheep manure have the potential to serve as a sustainable soil management strategy that can reduce dependence on chemical fertilizers and support food security in marginal lands.

LIMITATIONS & FURTHER RESEARCH

This study still has certain limitations, as it has not yet determined the extent to which biochar and sheep manure have a significant effect on maize growth due to the unavailability of data on nutrient uptake in plant tissues. Therefore, further research is needed to analyze nutrient uptake in plant tissues, as well as to examine the application of biochar and sheep manure combinations to other food crops. In addition, an economic feasibility analysis is required, taking into account the costs of biochar production, crop maintenance, and pest and disease management.

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