

Biochar and Humic Acid Effects on Soil Properties and Soybean Growth in Coastal Sandy Soil

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Abstract

Coastal sandy soil remains constrained by its low capacity to retain water and essential nutrients, particularly nitrogen, which is highly susceptible to leaching. This study aimed to evaluate the effects of rice husk biochar and humic acid application on soil chemical properties and their relationship with soybean growth. The experiment was conducted at the Research Farm of the Faculty of Agriculture, Universitas Pembangunan Nasional "Veteran" Yogyakarta, using a Completely Randomized Design (CRD) with a two-factor factorial arrangement and three replications, resulting in 48 experimental units. The first factor was rice husk biochar (B) at four dosage levels, and the second factor was humic acid (H) at four dosage levels. The results showed that rice husk biochar and humic acid application improved soil organic C, cation exchange capacity (CEC), and total nitrogen, which was followed by better soybean growth. The highest values were observed under the B3H3 treatment (20 ton ha⁻¹ biochar and 3,15 L ha⁻¹ humic acid). This combination increased soil organic C from 0.51% to 1.11%, CEC from 1.1 cmol(+) kg⁻¹ to 1.72 cmol(+) kg⁻¹, and total nitrogen from 0.21% to 0.44%. The improved soil chemical fertility was accompanied by better soybean performance, with a plant height of 88.72 cm, 27 leaves, and 23.67 pods per plant. Overall, applying rice husk biochar and humic acid improved soil chemical properties, particularly organic C, CEC, and total nitrogen, thereby supporting soybean growth.

Keywords Biochar, Coastal Sandy Soil, Humic Acid, Nitrogen Availability, Soybean (*Glycine max*)

INTRODUCTION

Soybean (*Glycine max* L.) production in Indonesia remains insufficient to meet national consumption, resulting in continued dependence on imports (Statistics Indonesia (BPS), 2025; Ministry of Agriculture, 2024). Increasing soybean productivity is therefore important for supporting national food security, including by utilizing coastal sandy soils. However, coastal sandy soils have several limitations, including a high sand fraction, low organic matter and cation exchange capacity, and limited ability to retain water and nutrients (Musei et al., 2024).

Nitrogen is an essential nutrient involved in forming proteins, enzymes, nucleic acids, and chlorophyll, supporting vegetative plant growth (Hulu et al., 2026). Nitrogen availability in sandy soils is often low because nutrients are easily lost through leaching due to high infiltration rates and limited nutrient retention capacity (Bekchanova et al., 2024). Soil amendments such as rice husk biochar and humic acid can improve nutrient retention and availability in sandy soils. Bekchanova et al. (2024) and Rahim et al. (2024) also reported that biochar and humic acid can

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improve nutrient retention and availability in sandy soils.

Previous studies have demonstrated the potential of biochar and humic acid to improve soil properties and plant growth. [Bekchanova et al. \(2024\)](#) reported that biochar can improve nutrient cycling and crop productivity in sandy-textured soils, while [Rahim et al. \(2024\)](#) highlighted the potential of combining biochar with humic substances for improving soil quality and nutrient retention. In soybean cultivation, [Supriyadi et al. \(2022\)](#) found that rice husk biochar combined with cow manure improved soil characteristics, nutrient uptake, and plant growth in Alfisol, whereas [Yati et al. \(2024\)](#) reported positive effects of rice husk biochar combined with liquid organic fertilizer on soybean growth and yield in Entisol. Humic acid has also been reported to improve soybean growth and yield attributes ([Sohail et al., 2025](#)). However, these studies have primarily examined biochar or humic acid in soils other than coastal sandy soil, or have evaluated biochar in combination with other organic inputs rather than humic acid. Therefore, the combined application of rice husk biochar and humic acid and its effects on soil nitrogen status and soybean growth in coastal sandy soil remain insufficiently explored. This study aims to evaluate the effects of rice husk biochar and humic acid application on soil nitrogen availability and soybean growth in coastal sandy soil from Samas Beach.

LITERATURE REVIEW

Coastal sandy soils are characterized by coarse texture, low organic matter, and low cation exchange capacity, which limits water and nutrient retention. These characteristics make nutrient management particularly important for crop production on sandy soils. Nitrogen is one of the nutrients most susceptible to loss from sandy soils because of their high infiltration rates and limited nutrient-retention capacity. Therefore, coastal sandy soils need soil amendments that improve nutrient retention and soil chemical properties to support crop production.

Biochar has been widely studied as a soil amendment for improving the properties of sandy and degraded soils. [Bekchanova et al. \(2024\)](#), through a systematic review, reported that biochar can improve nutrient cycling in sandy-textured soils and contribute to increased crop productivity. The positive effects of biochar are associated with its relatively stable carbon, porous structure, and surface functional groups, which can support nutrient retention and improve soil chemical properties. [Romadhan et al. \(2022\)](#) reported similar findings, finding that rice husk biochar combined with chicken manure improved the chemical properties of former gold-mining soil. [Herlambang et al. \(2020, 2023\)](#) also reported the potential of biochar as a soil amendment for improving soil and environmental conditions. However, biochar responses can vary depending on soil characteristics and the materials combined with it. Thus, findings obtained from degraded or non-coastal soils cannot necessarily be directly applied to coastal sandy soils.

Previous studies have also examined rice husk biochar use in soybean cultivation. [Supriyadi et al. \(2022\)](#) reported that rice husk biochar combined with cow manure improved soil characteristics, nitrogen and phosphorus uptake, and soybean growth in Alfisol. [Yati et al. \(2024\)](#) similarly found that applying rice husk biochar combined with liquid organic fertilizer affected soybean growth and yield in Entisol. These studies demonstrate the potential of rice husk biochar to support soybean production; however, they were conducted in Alfisol and Entisol, respectively, and the biochar was combined with cow manure or liquid organic fertilizer rather than humic acid. Therefore, the response of soybean to the combined application of rice husk biochar and humic acid in coastal sandy soil remains insufficiently investigated.

Humic acid has also been investigated as a soil conditioner because of its functional groups and its potential to improve nutrient retention and plant performance. [Rahim et al. \(2024\)](#) reviewed the combination of biochar with humic substances and highlighted their potential implications for sustainable soil and nutrient management. [Saptiningsih et al. \(2026\)](#) reported that humic acid

application improved drought tolerance and vegetative growth of mung bean in sandy soil, indicating its potential for improving plant performance under sandy-soil conditions. In soybean, [Sohail et al. \(2025\)](#) reported that humic acid application positively affected yield and related attributes. However, these studies considered either humic acid or its combination with biochar in different soil and crop contexts, and did not specifically evaluate the interaction between rice husk biochar and humic acid in coastal sandy soil planted with soybean.

These amendments are particularly relevant to nitrogen management in sandy soils. Biochar may improve nitrogen retention through its porous structure and surface properties, while humic substances may contribute to nutrient retention and improve nitrogen use efficiency. [Herlambang et al. \(2020\)](#) reported biochar's potential to reduce nutrient losses, while [Rahmandhias and Rachmawati \(2020\)](#) found that humic acid application affected nitrogen use efficiency and nitrogen uptake in water spinach. Nevertheless, evidence on the combined effects of rice husk biochar and humic acid on soil nitrogen status and soybean growth under coastal sandy-soil conditions remains limited. The interaction between these two amendments is therefore an important area for further investigation, particularly in coastal sandy soil from Samas Beach.

RESEARCH METHOD

This research was conducted at the Experimental Garden of the Faculty of Agriculture, Universitas Pembangunan Nasional "Veteran" Yogyakarta, using coastal sandy soil originating from Samas Beach, Bantul Regency, Special Region of Yogyakarta. The study used a Completely Randomized Design (CRD) with two factors in a factorial arrangement. The first factor was the dose of rice husk biochar (B), consisting of four levels: B0 (0 tons ha⁻¹), B1 (10 tons ha⁻¹), B2 (15 tons ha⁻¹), and B3 (20 tons ha⁻¹). The second factor was the dose of humic acid (H), consisting of four levels: H0 (0 L ha⁻¹), H1 (1.575 L ha⁻¹), H2 (2.10 L ha⁻¹), and H3 (3.15 L ha⁻¹). Each treatment combination was replicated three times, resulting in 48 experimental units. Soil organic C, CEC, and total N were analyzed using the Walkley and Black, NH₄OAc saturation, and Kjeldahl methods, respectively, following [Eviati and Sulaeman \(2009\)](#).

Before analysis, soil samples were air-dried, gently ground, and passed through a 2-mm sieve. For organic C analysis, the soil sample was oxidized using the Walkley and Black procedure, and organic C content was determined from the amount of oxidized carbon. CEC was determined using NH₄OAc saturation, in which soil exchange sites were saturated with NH₄⁺ and the exchange capacity was subsequently determined. Total N was analyzed using the Kjeldahl procedure involving sample digestion, distillation, and determination of nitrogen content. The analytical results were expressed as percentages of organic C and total N, and cmol(+) kg⁻¹ for CEC. Detailed analytical procedures followed [Eviati and Sulaeman \(2009\)](#).

Each experimental unit consisted of one observed plant, so the total number of observed plants was 48. The growth parameters observed included plant height, number of leaves, and number of pods. Plant growth observations were conducted weekly, beginning one week after planting and continuing until harvest. Plant height was measured from the base of the stem to the growing point, while the number of leaves and pods was counted directly on each sample plant. Data were analyzed using analysis of variance (ANOVA) at the 5% significance level. When treatments showed a significant effect, the analysis was continued with Duncan's Multiple Range Test (DMRT) at the 5% level. Data were processed using Microsoft Excel Professional Plus 2019, Microsoft Office Professional Plus 2019, and SAS 9.4.

FINDINGS AND DISCUSSION

C-Organic

Applying rice husk biochar and humic acid increased soil organic C content compared with

the initial condition, with values varying across treatment combinations (Table 1).

Table 1. Average Soil Organic C under Rice Husk Biochar and Humic Acid Treatments

Rice husk biochar (ton/ha)	Humic acid (lt/ha)				Average (%)
	H0 (0)	H1 (1,575)	H2 (2.10)	H3 (3.15)	
B0 (0)	0.51	0.73	0.75	0.78	0.74 d
B1 (10)	0.82	0.83	0.87	0.90	0.86 c
B2 (15)	0.91	0.94	0.95	0.96	0.94 b
B3 (20)	1.00	1.01	1.03	1.11	1.04 a
Average (%)	0.86 q	0.88 pq	0.90 pq	0.94 p	(-)

Information:

Numbers followed by the same letter in both columns and rows indicate no significant difference in the 5% DMRT test. A (-) sign indicates no interaction.

Organic C content increased gradually with increasing biochar dosage and peaked at 1.04% at dosage B3 (Table 1). This increase is related to biochar, which contains relatively stable carbon, making it more resistant to decomposition and increasing soil organic C content (Sirait et al.,2020). Humic acid is a fraction of organic matter containing active functional groups and can contribute to increased soil organic carbon accumulation. In addition to biochar and humic acid, additional organic C also came from the organic fertilizer (POC) used in the study, with an organic C content of 1.40% (Table 1). The combination of 20 tons ha⁻¹ rice husk biochar and 3.15 L ha⁻¹ humic acid (B3H3) increased the organic C value from 0.51% to 1.11%. (Figure 1).

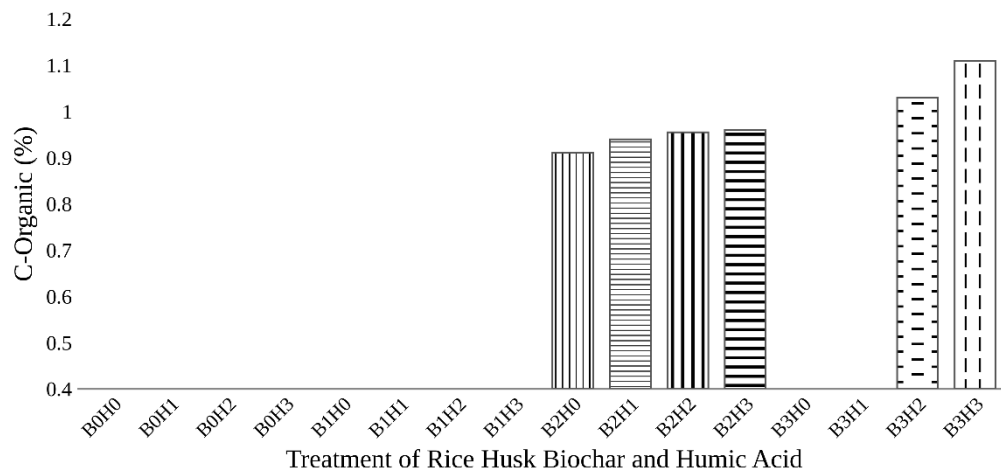


Figure 1. Effect of Rice Husk Biochar and Humic Acid Application on the Organic C Content of Samas Beach Sandy Soil, Yogyakarta, Indonesia

Cation Exchange Capacity (CEC)

Rice husk biochar and humic acid application increased CEC compared with the initial condition, with values varying across treatment combinations (Table 2). This improvement indicates that applying rice husk biochar and humic acid can enhance CEC in Samas Beach soil.

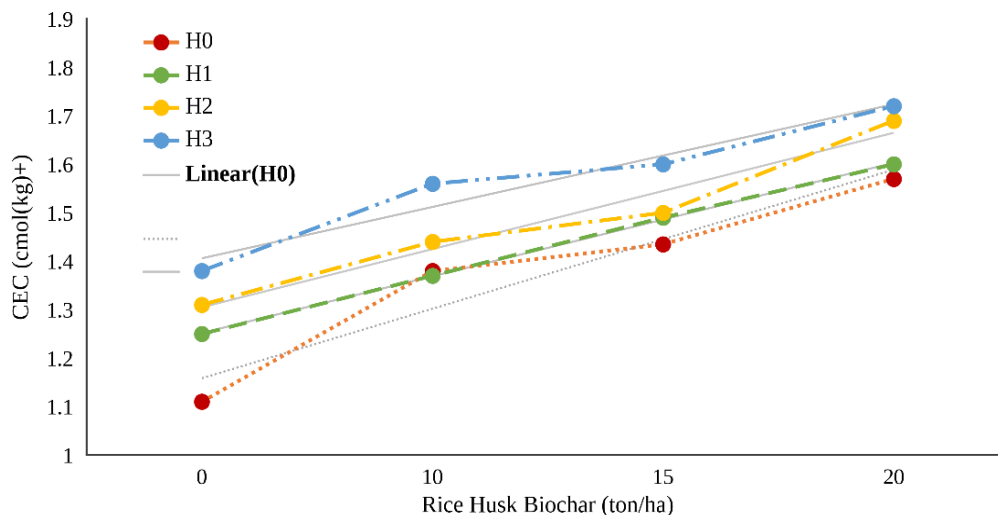
Table 2. Average CEC under Rice Husk Biochar and Humic Acid Treatments

Rice husk biochar (ton/ha)	Humic acid (lt/ha)				Average (cmol(+)kg ⁻¹)
	H0 (0)	H1 (1,575)	H2 (2.10)	H3 (3.15)	
B0 (0)	1.1 fb	1.25 ef	1.31 e	1.38 de	1.29
B1 (10)	1.38 de	1.37 de	1.44 cd	1.56 ab	1.44
B2 (15)	1.44 cd	1.49 bc	1.50 bc	1.54 c	1.48
B3 (20)	1.57 ab	1.60 ab	1.69 a	1.72 a	1.65
Average (cmol(+)kg ⁻¹)	1.41	1.43	1.49	1.53	(+)

Information:

Numbers followed by the same letter in both columns and rows indicate no significant difference in the 5% DMRT test. The (+) sign indicates an interaction.

Applying rice husk biochar and humic acid increased soil cation exchange capacity (CEC) compared with the untreated control, with the highest values at doses B3 and H3 (Table 2). The increase in CEC from biochar is attributed to its surface area and pore structure, which increase soil organic matter and negative charge, thereby increasing the soil's ability to absorb and retain cations. These findings align with [Putri and Herlambang \(2025\)](#), who reported that biochar application increases soil CEC by adding negative colloidal charge and soil organic matter. The increase in CEC due to humic acid is related to carboxylate and phenolic functional groups, which increase the negative charge of soil colloids and enhance the soil's capacity to absorb and retain cations. The increase in CEC from these two soil amendments indicates improved nutrient retention, which in turn supports increased nutrient availability for plants. The combination of 20 tons ha⁻¹ rice husk biochar and 3.15 L ha⁻¹ humic acid (B3H3) can increase CEC from 1.1 cmol (kg)⁻¹ to 1.72 cmol (kg)⁻¹ (Figure 2).

**Figure 2.** Effect of Rice Husk Biochar and Humic Acid Application on the Cation Exchange Capacity (CEC) in the Samas Beach Sandy Soil, Yogyakarta, Indonesia

Total Nitrogen

Rice husk biochar and humic acid application increased soil total N compared with the initial condition, with values varying across treatment combinations (Table 3).

Table 3. Average Total N under Rice Husk Biochar and Humic Acid Treatments

Rice husk biochar (ton/ha)	Humic acid (lt/ha)				Average (%)
	H0 (0)	H1 (1,575)	H2 (2.10)	H3 (3.15)	
B0 (0)	0.21 i	0.25 i	0.29 hi	0.31 gh	0.27
B1 (10)	0.30 gh	0.33 ef	0.32 fg	0.36cde	0.33
B2 (15)	0.35 de	0.35 de	0.38 bc	0.37 cd	0.36
B3 (20)	0.38 bc	0.39 abc	0.42 ab	0.44 a	0.41
Average (%)	0.32	0.33	0.35	0.37	(+)

Information:

Numbers followed by the same letter in both columns and rows indicate no significant difference in the 5% DMRT test. The (+) sign indicates an interaction.

Biochar may increase total N by enhancing nitrogen retention and providing habitat for microbial activity, while humic acid improves N retention and reduces nitrogen loss ([Herlambang et al., 2020](#)). Meanwhile, humic acid increases the soil's ability to retain nitrogen, particularly by improving cation exchange capacity and its ability to bind NH_4^+ ions. This result is consistent with [Rahmandhias and Rachmawati \(2020\)](#), who stated that humic acid application can increase nitrogen use efficiency and reduce nitrogen loss in the soil.

The interaction between rice husk biochar and humic acid shows that the combination of the two materials influences the total N response. The B3H3 combination produced the highest total N (0.44%), while B0H0 produced the lowest (0.21%) (Table 3). This increase in total N at the highest-dose combination indicates that applying biochar and humic acid together can enhance the soil's ability to retain nitrogen. The POC fertilizer also contained 0.40% N and may have contributed to soil N. The combination of 20 tons ha^{-1} rice husk biochar and 3.15 L ha^{-1} humic acid (B3H3) increased the N-total value from 0.21% to 0.44%.

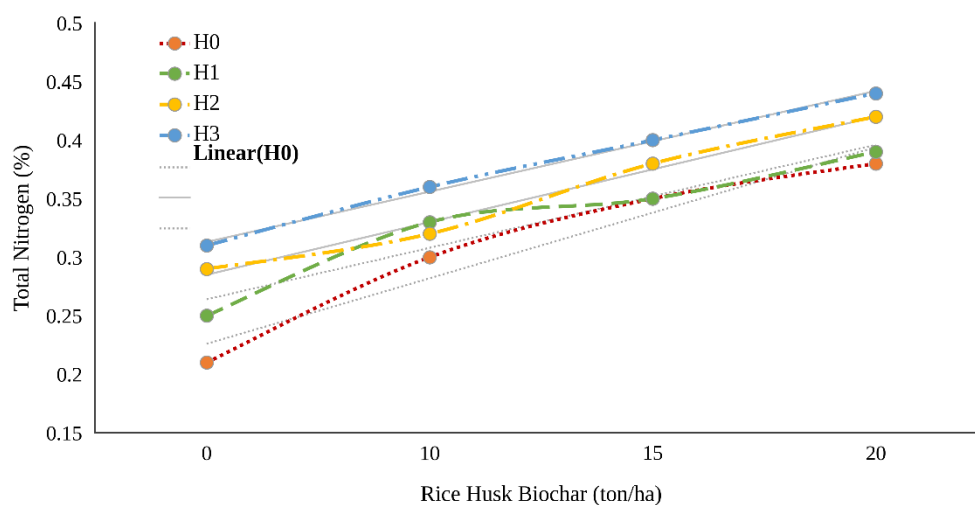


Figure 3. Effect of Rice Husk Biochar and Humic Acid Application on Total Nitrogen of Samas Beach Sandy Soil

Plant Height

Plant height varied among treatments and increased under the combined application of biochar and humic acid. This finding is consistent with [Supriyadi et al. \(2022\)](#), who reported that rice husk biochar application enhanced soybean growth by improving soil characteristics and increasing nutrient availability. Humic acid application can increase soybean plant height ([Sohail et al., 2025](#)). Based on the results, the treatment with rice husk biochar at 20 tons ha^{-1} and humic acid at 3.15 L ha^{-1} (B3H3) showed the highest average plant height of 88.72 cm.

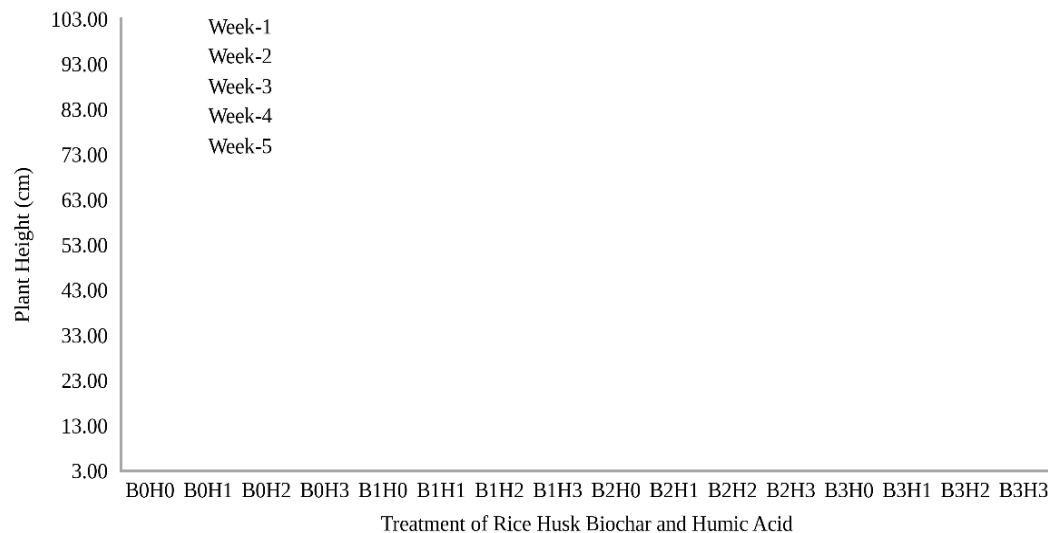


Figure 4. Plant Height of Soybean under Rice Husk Biochar and Humic Acid Treatment

Legend:

B0= Dose of 0 tons/ha of rice husk biochar equivalent with 0 g/5 kg soil

B1= Dose of 10 tons/ha of rice husk biochar equivalent with 24.3 g/5 kg soil

B2= Dosage of 15 tons/ha of rice husk biochar equivalent with 36.4 g/5 kg soil

B3 = Dose of 20 tons/ha of rice husk biochar equivalent with 48.6 g/5 kg soil

H0= Dose 0 lt /ha humic acid equivalent with 0 ml/ lt

H1= Dose 1.575 lt /ha humic acid equivalent with 15 ml/ lt

H2= Dose 2.10 lt / ha humic acid equivalent with 20 ml/ lt

H3= Dose 3.15 lt / ha humic acid equivalent with 30 ml/ lt

Number of Leaves

The number of leaves also varied among treatment combinations. These findings are consistent with Yati et al. (2024), who reported that applying rice husk biochar significantly affected the number of leaves on soybean plants. Humic acid application can increase the number of leaves on soybeans ([Sohail et al., 2025](#)). Based on the observation results, the treatment of rice husk biochar at a dose of 20 tons ha^{-1} and humic acid dose of 3.15 L ha^{-1} (B3H3) showed the highest average number of leaves, namely 27 leaves.

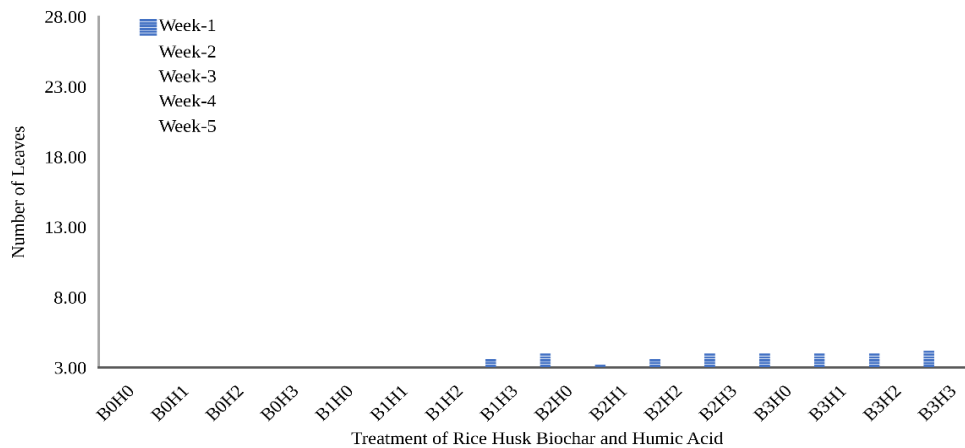


Figure 5. Number of Leaves of Soybean under Rice Husk Biochar and Humic Acid Treatment

Legend:

B0= Dose of 0 tons/ha of rice husk biochar equivalent with 0 g/5 kg soil

B1= Dose of 10 tons/ha of rice husk biochar equivalent with 24.3 g/5 kg soil

B2 = Dose of 15 tons/ha of rice husk biochar equivalent with 36.4 g/5 kg soil

B3 = Dose of 20 tons/ha of rice husk biochar equivalent with 48.6 g/5 kg soil

H0= Dose 0 lt /ha humic acid equivalent with 0 ml/ lt

H1= Dose 1.575 lt /ha humic acid equivalent with 15 ml/ lt

H2= Dose 2.10 lt / ha humic acid equivalent with 20 ml/ lt

H3= Dose 3.15 lt / ha humic acid equivalent with 30 ml/ lt

Number of Pods

A similar pattern was observed for the average number of pods, which varied across treatment combinations of rice husk biochar and humic acid applied to the soybean planting medium. Based on the observation results, the treatment of rice husk biochar at a dose of 20 tons ha^{-1} and humic acid dose of 3.15 L ha^{-1} (B3H3) showed the highest average number of pods, namely 23.67 pods.



Figure 6. Number of Pods of Soybean under Rice Husk Biochar and Humic Acid Treatment

Legend:

B0= Dose of 0 tons/ha of rice husk biochar equivalent with 0 g/5 kg soil

B1= Dose of 10 tons/ha of rice husk biochar equivalent with 24.3 g/5 kg soil

B2 = Dose of 15 tons/ha of rice husk biochar equivalent with 36.4 g/5 kg soil

B3 = Dose of 20 tons/ha of rice husk biochar equivalent with 48.6 g/5 kg soil

H0= Dose 0 lt /ha humic acid equivalent with 0 ml/ lt

H1= Dose 1.575 lt /ha humic acid equivalent with 15 ml/ lt

H2= Dose 2.10 lt / ha humic acid equivalent with 20 ml/ lt

H3= Dose 3.15 lt / ha humic acid equivalent with 30 ml/ lt

CONCLUSIONS

Applying rice husk biochar and humic acid improved the chemical properties of coastal sandy soil and supported soybean growth. The combined application positively affected soil organic C, cation exchange capacity (CEC), total N, plant height, number of leaves, and number of pods. Among the treatments, B3H3, consisting of 20 ton ha⁻¹ rice husk biochar and 3.15 L ha⁻¹ humic acid, produced the highest values, with 1.11% organic C, 1.72 cmol(+) kg⁻¹ CEC, 0.44% total N, 88.72 cm plant height, 27 leaves, and 23.67 pods.

These findings indicate that combining rice husk biochar and humic acid has potential as a soil amendment strategy to improve the chemical properties of coastal sandy soils and support soybean production. The results contribute to existing research by providing evidence of the potential interaction between rice husk biochar and humic acid under coastal sandy-soil conditions, which have received less attention than other soil types. In practical terms, these amendments may be considered as part of soil management strategies to improve the fertility and productivity of coastal sandy soils, particularly by increasing organic matter and nutrient-retention capacity.

LIMITATIONS & FURTHER RESEARCH

The results were obtained under controlled pot conditions and during a single growing season. Therefore, further research should evaluate the effectiveness of rice husk biochar and humic acid under field conditions, including their residual effects over multiple growing seasons, as well as the economic feasibility of their application for soybean production in coastal sandy soils.

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