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Effect of Rice Husk and Bamboo Biochar on Soil Compaction in Paddy Fields under Varying Moisture Conditions

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ABSTRACT

Soil compaction impacts the physical quality of paddy fields by hindering water infiltration, limiting aeration, and stunting root growth. The use of biochar has emerged as a promising approach to mitigate soil compaction and improve soil structure. This study aimed to investigate the effects of rice husk and *petung* bamboo biochar on soil compaction at different moisture levels. Laboratory assays employing standard compaction tests of soils were performed, and the resulting data were subjected to quadratic regression analysis. Both rice husk and *petung* bamboo biochars showed a quadratic relationship between soil moisture and compaction with R^2 values of 0.8512 and 0.9913, respectively. Also, rice husk biochar lowered soil compaction so that bulk density decreased from 1.393937 $g.cm^{-3}$ at 27% (w/w) moisture to 1.2006 $g.cm^{-3}$ at 41% (w/w) moisture. Meanwhile, soil with *petung* bamboo biochar reached a maximum bulk density of 1.3806 $g.cm^{-3}$ at 36% (w/w) moisture and was stable at higher moistures. The effectiveness of biochars in reducing soil compaction is attributed to their physical properties such as porosity and density. From the results, it is suggested that the application of rice husk biochar effectively improves paddy field soil structure and supports sustainable agriculture practices.

Keywords: Soil Compaction; Biochar; Rice Husk Biochar; Bamboo Biochar; Bulk Density; Optimum Moisture Content; Moisture Content; Paddy Field; Soil Physical Properties; Sustainable Agriculture.

1. Introduction

Soil forms through the disintegration of rocks accompanied by the decomposition of plant and animal remains. It constitutes a very important natural heritage as it is made of minerals and organic matter. It is the basic medium for plant growth and serves great value in agriculture (Manullang et al., 2020). In Indonesia, paddy fields are of great importance for the country's food self-sufficiency. To sustainably produce rice, innovative and environmentally considerate agriculture practices have to be adopted. The use of farming machinery in paddy fields is on the rise, which results in soil compaction. As noted by Waruwu & Gulo (2024), soil compaction is a difficult problem in paddy farming where the practice of deep tillage and the continuous use of heavy machines contribute a lot to the problem. Compacted soils are characterized by less pore space, poor water absorption, and limited root growth as well as stunted plant growth which ultimately leads to reduced crop yields (Ogorek et al., 2025). Prior research has shown that soil compaction negatively affects the growth of roots, resulting in reduced root length and volume, diminished biomass, and impaired capability to absorb water and nutrients (Waruwu & Gulo, 2024).

Biochar is an organic amendment created by pyrolysis of biomass at elevated temperatures and in low oxygen environments. It has exceptional advantages in improving soil structure and decreasing compaction. Application of biochar has been shown to decrease soil bulk density, and soil compaction while increasing soil porosity, aeration, and root development. In addition, biochar aids in long-term carbon sequestration which underpins sustainable agriculture (Blanco-Canqui, 2021). Of the possible biochar feedstocks, rice husk and petung bamboo (Dendrocalamus asper) stand out as more viable options (Blanco-Canqui, 2021; Zhu et al., 2023). Rice husk, which is generated during the milling of rice, contains copious amounts of silica, enabling it to function as a soil amendment, yet it is severely underprotected. Petung bamboo bodes well in this regard since its high lignocellulosic structure allows it to produce biochar with high carbon and silicon content, as well as considerable structural porosity and beneficial qualities (Alfiandari et al., 2023). The use of biochar derived from rice husks and petung bamboo is anticipated to enhance soil structure by alleviating soil compaction in paddy fields. Soil compaction describes a process in which soil particles are squeezed together due to physical forces resulting in a decrease in pore spaces and an increase in bulk density. Soil moisture content influences this process significantly.

With a lower amount of water, soils become more resistant to compaction. Nevertheless, as soil moisture increases, water will reduce inter-particle friction acting as lubricant, making the soil easier to compact under any external load. Darusman et al (1991) showed that the amount of water which yields maximum bulk density of soil is the optimum water content for compaction. Under a particular compactive effort, dry bulk density increases to maximum value with increase in water content and then decreases with further addition of water. This relationship is of great importance in agriculture where the traffic of heavy machinery over moist soils can cause intense compaction which may damage the soil structure as well as soil aeration.

Soil compaction also affects the dynamics of soil water. Soils that are compacted also have low macro-porosity, which is the growth of pore spaces that allow water to flow, hindering water infiltration while increasing surface runoff (Horn et al., 1995). This may lead to perched water tables, decreased soil permeability, poor drainage and low oxygen, restricted drainage, low-root oxygen stunting roots. Thus, the association between compaction and soil moisture content strongly influences the balance of soil health and sustainability in agricultural productivity.

This research concentrated on the effects of biochar from rice husk and petung bamboo on soil compaction at varying moisture contents.

1.1. Study Objectives

The objectives study in this research consisted of: (1) Examining how rice husk biochar influences soil compaction in paddy fields. (2) Analyzing the compaction properties of soil enhanced with rice husk and bamboo biochar. (3) Obtaining optimal moisture content and maximum compaction in rice fields after biochar application. (4) Examining compaction curves for soil samples with and without biochar treatment. (5) Assessing which kind of biochar is better at decreasing compaction.

2. Materials and Methods

2.1. Materials

In the study, the materials consisted of petung bamboo (Dendrocalamus asper) biochar, rice husk biochar, and paddy field soil. The biochars were obtained from Pusat Riset Biochar Universitas Syia Kuala, Banda Aceh, while the soil samples were taken from Peukan Biluy, Aceh Besar, Indonesia (5°29'08.3"N 95°20'02.8"E). The soil was air-dried and sieved to remove large particles before testing.

2.2. Methods

2.2.1. Soil Sample Preparation

The soil for compaction study was sieved to remove stones and debris, then divided into experimental groups according to the treatments. The soil was thoroughly mixed to ensure uniformity before biochar application.

2.2.2. Biochar Application

The biochar was ground and sieved to obtain uniform particle sizes of 0.5–2 mm. It was applied at 3% by weight to the soil samples. The *rice husk* and *petung* bamboo biochar were manually mixed into the soil, followed by mechanical mixing to ensure even distribution. A control treatment without biochar was also prepared.

2.2.3. Moisture Content Treatment

The soil moisture content was adjusted to four levels: 0.1, 0.2, 0.3, and 0.4 $g.g^{-1}$. Water was added gradually while mixing to achieve uniform moisture distribution without over-saturation. The soil samples were then placed into compaction mold for testing.

2.2.4. Soil Compaction Measurement

Soil compaction was measured using a soil compaction device. The study was aimed to determine the optimum water content for compaction and the maximum bulk density under a given compactive effort which described by Felt (1965). Soil bulk density ($g.cm^{-3}$) at different water content was determined by using a mold (10.2 cm in diameter and 11.6 cm tall) and a 2.49 kg rammer. The soil samples were compacted in three equal layers and each layer received 25 blows of the rammer dropped from the height of 30.5 cm above the soil surface. All measurements were performed in triplicate.

The optimum water content for compaction and the maximum bulk density were found by using a regression equation determined with regression of bulk density values (dependent variables) against water content (independent variables).

3. Results and Discussion

3.1. Effect of Biochar on Soil Compaction

The control soil (blank sample) without biochar had the highest compaction value of 1.3939 $g.cm^{-3}$ at 27% moisture level (w/w). Soils treated with biochar showed lower compaction. With 41% moisture content, rice husk biochar achieved the best result with bulk density of 1.2006 $g.cm^{-3}$ lowered compaction the most. This result stems from biochar having a porous structure, which improves soil aeration and water retention while improving soil structure. The maximum compaction results and optimum moisture content for each treatment are presented in Table 1.

Table 1. Soil compaction for different treatments

Description	Optimum Moisture Content (% w/w)	Maximum Compaction ($g.cm^{-3}$)
Soil only (Control)	27	1.3939
Soil + *Rice Husk* Biochar	41	1.2006
Soil + *Petung Bamboo* Biochar	36	1.3806

3.2. Influence of Moisture Content on Soil Compaction

A quadratic relationship was observed between soil compaction and moisture content. Compaction increased with moisture up to an optimum level, followed by a decline at higher moisture levels due to reduced particle contact as water filled the pore spaces (Rahmat & Ismail, 2018; Spagnoli & Shimobe, 2020). Figure 1 illustrates this trend for different biochar treatments. As shown in Figure 1, the application of biochar reduced soil compaction compared to the control treatment.

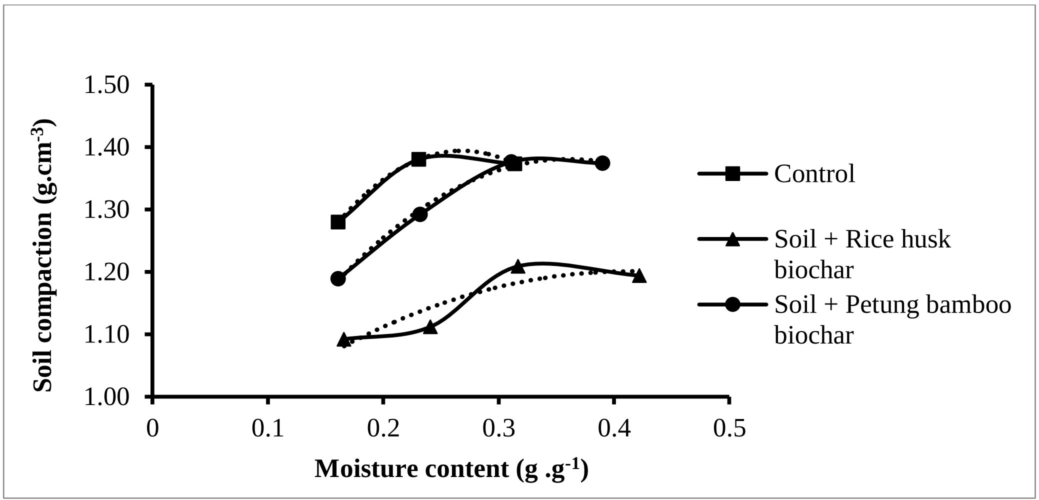

Figure 1. Soil compaction as influenced by biochar type and moisture content

3.3. Effect of *Rice Husk* Biochar on Soil Compaction

Rice husk biochar significantly reduced soil compaction across all moisture levels. Quadratic regression analysis revealed a strong fit ($R^2 = 0.8512$) for the relationship between moisture content and compaction. The compaction value (1.1940 g.cm^{-3}) occurred at 40% moisture content. These results align with previous studies demonstrating the effectiveness of *rice husk* biochar in improving soil porosity and reducing bulk density (Janu & Mutiara, 2021; Mishra et al., 2017; Wei et al., 2023). Figure 2 shows the compaction trend for *rice husk* biochar-treated soils. As shown in Figure 2, the application of biochar reduced soil compaction.

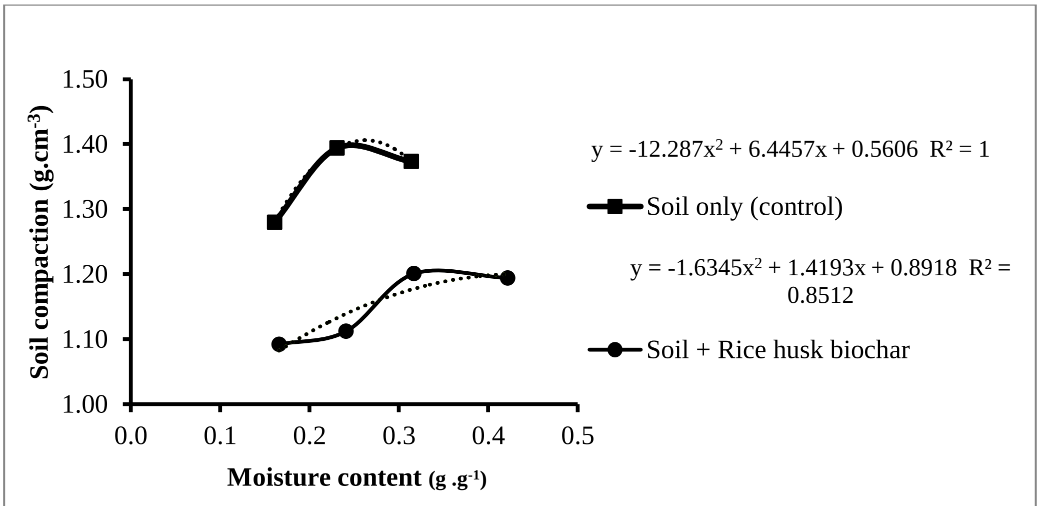

Figure 2. Soil compaction with *rice husk* biochar addition

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3.4. Effect of *Petung Bamboo* Biochar on Soil Compaction

Petung bamboo biochar also reduced soil compaction, though less effectively than *rice husk* biochar. The compaction's maximum value reached and maintained a figure of 1.3806 g.cm^{-3} at 36% moisture, tapering off slightly at 40% moisture. Strong model fit was also noted during regression analysis (R^2 = 0.9913). From these findings, it can be concluded that biochar porosity, which varies by feedstock, has a strong effect in reducing compaction (Bhat et al., 2022; Khan et al., 2024; Li et al., 2023). Figure 3 shows the compaction trend for *petung bamboo* biochar-treated soils. As shown in Figure 3, the application of biochar reduced soil compaction.

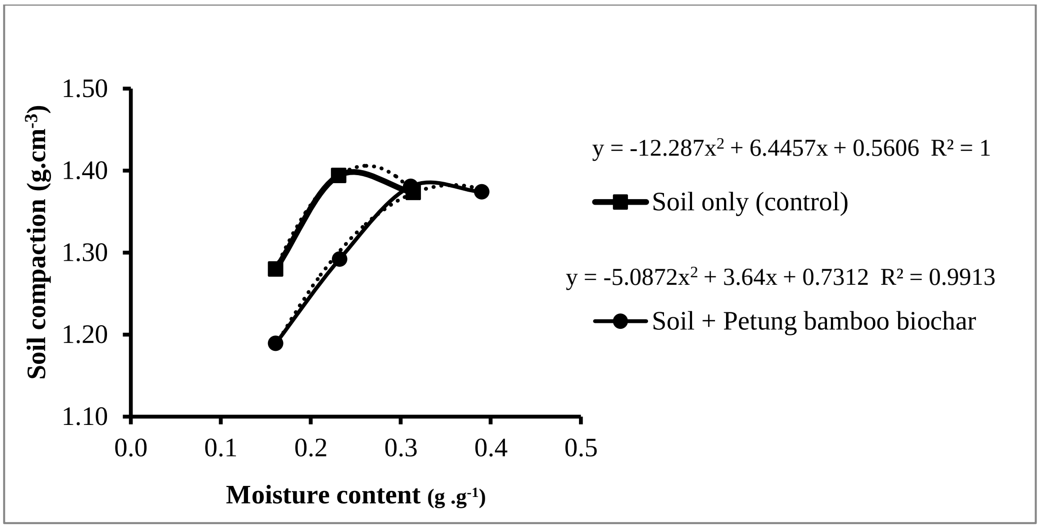

Figure 3. Soil compaction with *petung* bamboo biochar addition

4. Conclusion

The investigation showed that the type of biochar and moisture content significantly influences soil compaction in paddy fields. Compaction was lower when rice husk biochar was applied owing to its structural properties and water retention capability. The robust quadratic relationship between moisture content and compaction demonstrates that the water level in the soil should be moderated. The use of biochar, particularly rice husk biochar, seems to be a sustainable approach to improving soil structure, aeration, and the development of roots in rice-based farming systems.

Future research should investigate the lasting impacts of biochar on soil compaction, and also other varieties of biochar (such as those derived from coconut shells and corn cobs) need to be evaluated for comparison. An economic assessment of biochar usage in extensive rice cultivation can be performed to evaluate its practicality.

Declarations

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Competing Interests Statement

The author(s) declare that there is no conflict of interest regarding the publication of this article.

Consent for publication

All authors have read and approved the final manuscript for publication.

Authors' contributions

All the authors took part in literature review, analysis, and manuscript writing equally.

Availability of data and materials

Supplementary information is available from the authors upon reasonable request.

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Not applicable for this study.

Informed Consent

Not applicable for this study.

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