

Effectiveness of biochar size on physical properties of psamment soil

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ABSTRACT

Biochar's ability to improve the physical and hydrological properties of Psamment soil, which has a fine texture, depends heavily on its characteristics, including particle size. This study aimed to investigate the effect of biochar particle size on soil physical properties and water movement in Psamment soil. The research method employed a completely randomized design with biochar treatments prepared at pyrolysis temperatures of 450–500°C, divided into four dry sieve sizes: 2–1, 1–0.5, 0.5–0.1, and <0.1 mm, and mixed into the growing medium with Psamment soil at a 5% application rate. The growing media were incubated at room temperature for 21 days. This study included 1 control and 4 treatments with 5 replicates, for a total of 25 pot experiments. Water content was maintained at field capacity throughout the experiment. This experiment measured the physical properties of the soil. The results showed an improvement in soil physical properties, specifically an increase in clay content for biochar particles <0.5 mm; however, there was an increase in soil moisture and organic matter content with the application of biochar particles <2.00 mm. It could be concluded that soil physical properties could be influenced by the application of different biochar particle sizes, particularly regarding the soil's ability to retain water in Psamment soil.

Keywords: biochar, fractionation, hydrology, physics, size

INTRODUCTION

Most Psamment soils used for sustainable agriculture are hampered by several constraints due to low nutrient and organic matter content. In addition, light-textured soils in dry areas are characterised by poor soil structure that leads to inadequate physical conditions, increased soil density, reduced hydraulic conductivity, and low water retention, which affect plant growth and reduce agricultural production. Biochar is a black, carbon-rich solid residue that is usually produced by pyrolysis, under oxygen-limited conditions, of various agricultural biomass, manure, and urban waste (Adrinal et al., 2024). Biochar has been widely used as a soil amendment to improve the chemical and physical properties of soil (Mahmood et al., 2025). One of the main advantages of biochar over other forms of crop residue and organic amendments is that it

is more resistant to microbial degradation and mineralisation in soil (Li et al., 2025).

The positive impact of biochar on soil physical properties is mainly due to its surface properties, which are characterised by a large surface area and a highly porous structure (Jiao et al., 2025). Several studies have shown that the application of biochar to light-textured soils (e.g., sand, loamy sand, and sandy loam) has significantly reduced the bulk density of the soil (Kamyab et al., 2025), improved soil pore structure (Yang et al., 2025), and increased soil aggregate stability (Rambhatla et al., 2025) (Obia et al., 2016). Biochar application has been shown to reduce soil saturated hydraulic conductivity, especially in light-textured soils (Alawa et al., 2025; Uppalapati et al., 2025). (Ajayi & Horn, 2016) reported a 23–82% reduction in the saturated hydraulic conductivity of fine sandy soils when amended with high application rates

(2–5%, W/W) of biochar. The soil's ability to retain more water also increased with biochar application; DeLuca et al. (2024) reported increased water-holding capacity due to the highly porous nature of biochar particles. The water content at field capacity (FC) increased by 15% with the application of 2% (W/W) biochar to a fine clay soil (Zahra et al., 2025). The effect of biochar amendment on the hydraulic properties of light-textured soils depends on several factors, including feedstock type, pyrolysis temperature, application rate, and biochar particle size (El-Fawal et al., 2025; Liu et al., 2017; Wang et al., 2018). In contrast, the effect of biochar particle size on soil hydraulic properties had received less research attention. The interaction of biochar particles with the soil matrix was highly dependent on the size of the biochar particles (Alghamdi et al., 2020).

(Blanco-Canqui, 2017) Biochar with smaller size is likely to have larger surface area and microporosity. (Xie et al., 2015), Therefore, it was likely to be more efficient in storing groundwater compared to biochar which has a larger particle size (Chen et al., 2017). (Głab et al., 2016) found an increase in water content at field capacity when sandy soil was amended with biochar characterised by a particle size of 0.5 mm. In addition, biochar was characterised by large intrapore spaces (pores within the particles), which can provide additional space for water retention beyond the space provided by the interpores (pores between particles) (Fadilah et al., 2021; Puspita et al., 2021; Ratmini et al., 2018). The application of different biochar particle sizes will change the interpore characteristics of the soil matrix in terms of pore volume, tortuosity, and connectivity, which in turn will affect water retention and transport in the soil (Wang et al., 2018). The research of this study was to investigate the effect of biochar particle size on the physical properties of the soil and water movement in Psamment soil.

MATERIALS AND METHODS

The research was conducted in Beringin Raya Village, Muara Bangkahulu District, Bengkulu City. Biochar production was conducted in the Soil Laboratory, Faculty of Agriculture,

University of Bengkulu. Initial and final soil analyses were conducted in the Soil Science Laboratory, Faculty of Agriculture, University of Bengkulu. This research method was a completely randomised design with biochar treatments prepared at a pyrolysis temperature of 450–5000C divided into four dry sizes: 2–1, 1–0.5, 0.5–0.1, and <0.1 mm and mixed in potting soil with Psamment soil at an application rate of 5%. This study had one control and four treatments with five replications, resulting in 25 experimental pots. This experiment measured soil physics.

Implementation

The soil used for the experiment is Psamment soil from coastal land in Bengkulu. The raws material used were rice husks. Rice husks were obtained from agricultural waste around Bengkulu City. Next, the rice husk waste was dried at room temperature (25 °C) for 7 x 24 hours (until air-dried) in the Laboratory of Soil Science, University of Bengkulu. After that, the rice husk was burned using the pyrolysis principle at a temperature of between 300–700⁰C (Wang et al., 2018) until the rice husk was dark black in color. or in the form of biochar. The finished biochar was sieved to the sizes 2mm, 1mm, and 0.5 mm according to the treatment size.

Incubation

Biochar was sieved into sizes of 2mm, 1mm, and 0.5mm, respectively. 0.1mm weighed 5% of the Absolute Dry Weight (BKM) (Arthur et al., 2015). Potting soil was incubated at room temperature for 21 days.

Observation

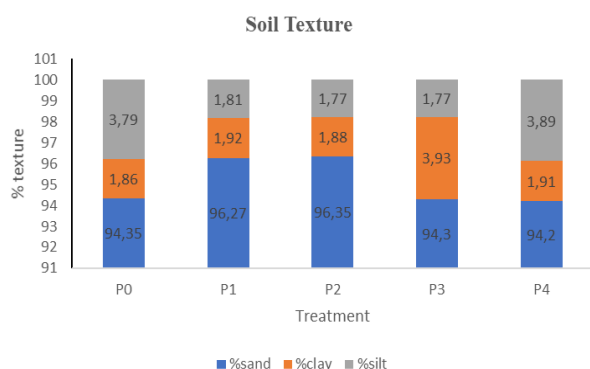
Initial soil samples and each treatment after incubation were analysed in the soil laboratory with parameters and methods (Table 1).

Table 1. Initial soil samples

Analysis	Metode
Physical Properties of Soil	
Textur	Sifting pipet
Permeability	Constant head parameter
Water content	Volumetric
Total pore space	Volumetric
Infiltration	Horton
Chemical Properties of Soil	
C-organic	Walkey and Black

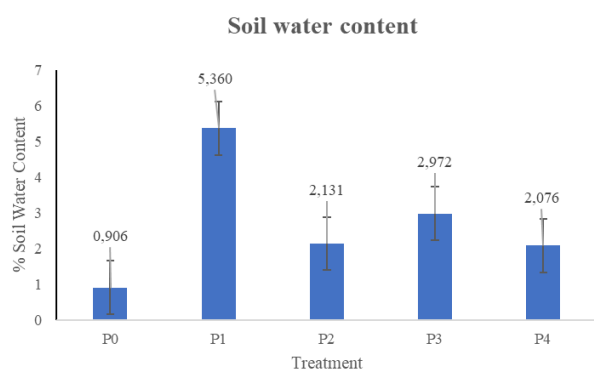
RESULTS

Laboratory test results show that the soil in the research area contains 0.19% N which was classified as low, 0.23% C-organic which was classified as moderate, 0.28 me/100 g of K₂O soil which was classified as low, 6.23 ppm P₂O₅ which is classified as low, with a pH value of H₂O of 6.2 which was classified as slightly acidic, a pH of KCl of 5.8 which was classified as slightly acidic, and a CEC of 5.21 me/100 g of soil which was classified as low. Based on these data, the soil at the research location was classified as marginal, with low nutrient content, organic matter, and CEC, and a slightly acidic pH. (Bertham et al., 2022; Bertham et al., 2020; Zikri et al., 2020) (Figure 1-5).



Note: PO (without biochar); P1 (biochar application size <2mm); P2 (biochar application size <1mm); P3 (biochar application size <0.5mm); and P4 (biochar application size 0.1mm)

Figure 1. Soil texture

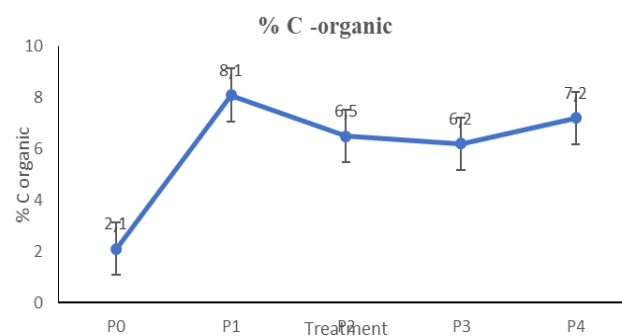


Note: PO (without biochar); P1 (biochar application size <2mm); P2 (biochar application size <1mm); P3 (biochar application size <0.5mm); and P4 (biochar application size 0.1mm)

Figure 2. Soil water content

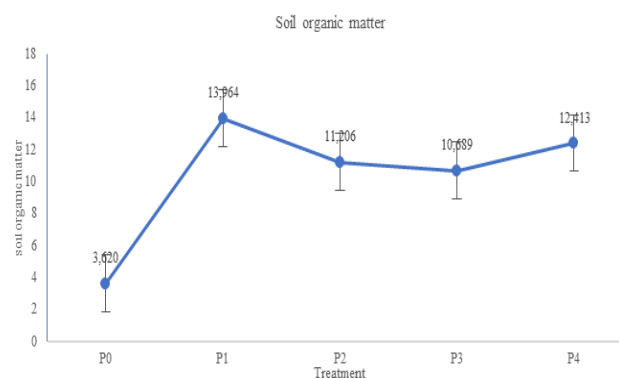
The soil organic carbon analysis also showed an increase in biochar content in the Psamment soil. However, Figure 3 showed that the peak value occurred when biochar was applied at a

size of <2 mm and decreased as biochar size decreased.



Note: PO (without biochar); P1 (biochar application size <2mm); P2 (biochar application size <1mm); P3 (biochar application size <0.5mm); and P4 (biochar application size 0.1mm)

Figure 3. Soil organic carbon



Note: PO (without biochar); P1 (biochar application size <2mm); P2 (biochar application size <1mm); P3 (biochar application size <0.5mm); and P4 (biochar application size 0.1mm)

Figure 4. Soil organic matter

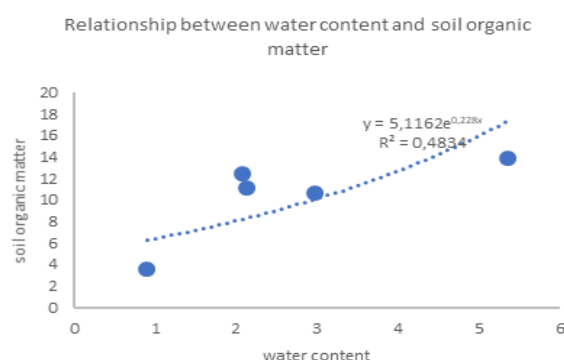


Figure 5. Water content and soil organic matter correlation

DISCUSSION

Soil texture analysis conducted after a 21-day incubation period of biochar on coastal Psamment soil in Bengkulu showed the development of sand, dust and clay fractions in

each treatment. The control soil texture contained 94.35% sand, 1.86% clay, and 3.79% silt. This contrasted with the soil conditions treated with biochar of each size. The sand fraction increased with biochar applications ranging from <2 mm to <1 mm. However, the sand fraction decreased again with applications of even smaller biochar sizes. The same was true for the silt and clay fractions. Soil surface area is an important soil characteristic as it controls all of the essential functions of soil fertility, including water and nutrient holding capacity, aeration, and microbial activity (Ashish & Salvi, 2019; Batool et al., 2015; Downie et al., 2009).

The limited water and nutrient holding capacity of sandy soil is partly related to the relatively small surface area of its soil particles (Sharma et al., 2021). Soils containing a large fraction of clay may have high total water and nutrients holding capacities but inadequate aeration (Yu et al., 2022). Biochar's surface area is generally higher than sand and comparable to or higher than clay; it will therefore increase the total soil-specific surface area when added as an amendment (Downie et al., 2009). Biochar incorporation into soil can enhance soil surface area up to 4.8 times that of adjacent soils (Liang et al., 2014). A long-term, 500-day soil column incubation experiment indicated increases in specific surface area (up to 18%) of an amended clayey soil when hardwood biochar was applied at rates up to 20 g/kg (Laird et al., 2010).

In addition, the high porosity of biochar can play important roles in augmenting physical quality of biochar-amended soil surface. Biochar application to infertile soil increases porosity through its porous internal structure and particle size and shape (Sparkes & Stoutjesdijk, 2011). The combined effect of biochar, clay, and soil organic matter may lead to the formation of micro-aggregates over time, which will improve soil porosity (Cheng et al., 2006; Rodowskia et al., 2006). The increase in porosity and hence surface area of biochar may also allow it to retain more moisture. It has been suggested that the low bulk density of biochar (~300 kg m³) and its highly stable organic carbon to soils has the potential to reduce soil bulk density and penetration resistance, and accordingly increase total soil porosity (Gwenzi et al., 2015). A

column experiment conducted by (Barnes et al., 2014) showed that addition of biochar decreased the bulk density of sand and clay by 17 and 20%, respectively. Applying wheat straw biochar to soil increased soil organic matter and reduced soil bulk density. In a two-year field study on rice, biochar amendment decreased soil bulk density in two consecutive cycles of rice growth (Zhang et al., 2012). A greenhouse trial in Spain with sunflower was designed to evaluate the effects of biochars produced from five different feedstock on soil properties (Alburquerque et al., 2014).

Biochar has been widely promoted as a way to improve a range of soil physical qualities through its effect on hydrological properties (i. e., water-holding capacity, moisture content, hydraulic conductivity, water retention, water infiltration rate) in biochar-amended soil (Barnes et al., 2014) (Baronti et al., 2014; Brantley et al., 2015; Devereux et al., 2013) (Laird et al., 2010) (Novak et al., 2012). (Laird et al., 2010) reported that hardwood biochar-amended soil showed greater water retention (up to 15%) at gravity-drained equilibrium and 100 and 500 kPa soil water potentials compared to un-amended controls. In a field study with Birch (*Betula* spp.) biochar incorporated into a silt loam soil in Finland, biochar addition increased water-holding capacity by 11% compared to the unamended control (Karhu et al., 2011) (Semida et al., 2019).

Important results are discussed, and the data found are interpreted. Similarities, differences, and uniqueness of the results obtained were compared with the latest information from previous studies (Zhang, 2012). If there are new findings, it should be stated firmly in the discussion. At the end of the discussion, the implications for related fields are presented.

Biochar structure comprises carbon, nitrogen, and hydrogen, and contains inorganic elements such as sodium, potassium, calcium, magnesium, iron, manganese, and silicon that provide unique chemical properties (He et al., 2020; Xu et al., 2013). The addition of biochar to soil typically causes an increase in soil pH and nutrient acquisition and therefore plays a role in improving plant nutrition and stress tolerance (Leng et al., 2020) (Akhil et al., 2021). Aliphatic, aromatic, hydroxyl, carboxyl, carbonyl, amide,

and acyl groups are common surface functional groups of biochar (Liu et al., 2019). They also influence the degree of sorption, pH buffering, surface charge (usually negative) and hydrophilicity or hydrophobicity alterations (El-naggar et al., 2019). Biochar surface area changes with porosity: <0.9 nm Nanopores, <2 nm micropores, and >50 nm macropores. These last facilitate microbe presence by promoting habitat niche and playing a vital role in soil aeration and hydrology, while smaller pores are involved in molecule adsorption (Marques et al., 2005).

CONCLUSION

This research is crucial to determine the optimal fractionation size and incubation duration of biochar types to improve the physical properties and water-holding capacity of Psammic soil, enabling appropriate and balanced application of ameliorants in farming communities. This research is also expected to create a technology model that can be widely adopted by the community to improve the soil quality of critical land and enable its conversion into productive land.

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