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The Effect of Cover Crop Presence on Soil Physical Properties Following Oil Palm Empty Fruit Bunch Biochar Application

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Abstract

Oil palm empty fruit bunch (EFB) biochar is a potential soil amendment, but its long-term effects may be influenced by cover crop species. This study evaluated soil physical properties at 8 and 19 months after biochar application and compared conditions under Cyperus rotundus (D1) and Nephrolepis biserrata (D2). The study was conducted at Division II of Adolina Estate, PTPN IV Regional II, using a quantitative descriptive method. Approximately 30% of the biochar remained visible on the soil surface. In Block L, bulk density decreased from 1.12 to 1.05 g cm^{-3}, while Block N remained stable at 1.04 g cm^{-3}. Porosity increased in Block L (57.74% to 61.82%) but decreased in Block N (60.75% to 60.00%). Soil moisture content declined in both blocks. Compared with C. rotundus, N. biserrata was associated with lower bulk density (1.26 vs. 1.36 g cm^{-3}), higher porosity (60.08% vs. 55.92%), and higher soil moisture content (49.06% vs. 46.77%). However, permeability was lower under N. biserrata (1.17 vs. 1.67 cm h^{-1}). Overall, N. biserrata was associated with more favorable soil physical conditions, particularly bulk density, porosity, and moisture retention, although responses varied among soil physical parameters.

Keywords: biochar; cover crops; *Cyperus rotundus*; *Nephrolepis biserrata*; soil physical properties

INTRODUCTION

Indonesia's oil palm industry generates substantial amounts of solid waste, particularly oil

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palm empty fruit bunches (EFB), which may pose environmental risks if not properly managed. An effective approach to EFB waste management that also creates added value is its conversion into biochar through pyrolysis (Darmono, 2017). Biochar has been widely utilized as a soil amendment, particularly to improve soil physical properties. Its porous structure can contribute to increased soil porosity and reduced bulk density, thereby improving the physical condition of the soil (Rauf et al., 2020).

Maharany (2021) reported that EFB biochar application significantly affected oil palm seedling growth parameters, which are closely associated with growing media conditions and soil physical properties, alongside improvements in nutrient availability. Similarly, Rauf (2020), in a study investigating the physical properties of Ultisols amended with biochar derived from oil palm residues, found that biochar application significantly reduced soil bulk density and increased soil porosity compared with untreated soil. These findings highlight the potential of EFB biochar to improve soil pore structure in oil palm plantations.

In addition to biochar, cover crops play an important role in maintaining and improving soil physical quality in oil palm plantations. Vani (2024) demonstrated that cover crop density influenced soil physical properties, including texture, bulk density, particle density, and porosity, as well as soil chemical properties such as pH and organic matter content. These findings are consistent with Ramadhan (2025), who reported that cover crops can improve soil structure by enhancing aggregate stability, porosity, aeration, and cation exchange capacity (CEC).

In oil palm cultivation, biochar application is often accompanied by cover crop establishment as part of land conservation practices. However, previous studies have generally examined the effects of EFB biochar and cover crops on soil physical properties separately (Maharany et al., 2021; Rauf et al., 2020; Vani et al., 2024; Ramadhan et al., 2025). The presence of cover crops in biochar-amended soil may influence changes in soil physical properties through organic matter inputs, protection of the soil surface against compaction, and regulation of soil moisture, potentially supporting the functions of biochar. Nevertheless, the combined effects of these practices remain insufficiently understood, particularly over extended periods following biochar application.

This study extends the research conducted by Alfazar (2025), which examined changes in soil physical properties at 2, 4, 6, and 8 months after biochar application. The present study evaluates soil physical properties at a later observation period to investigate the association between cover crop presence and the longer-term dynamics of soil physical properties following EFB biochar application. Therefore, this study aimed to evaluate the influence of cover crop

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presence on soil physical properties after EFB biochar application, providing a scientific basis for developing more effective soil management recommendations for oil palm plantations.

MATERIALS AND METHODS

Study Site and Period

This study was conducted at Division II of Adolina Estate, PTPN IV Regional II, Serdang Bedagai Regency, North Sumatra, Indonesia, from April to June 2026. Soil physical properties were analyzed at the Soil Science Laboratory, Faculty of Agriculture, Universitas Sumatera Utara. The study evaluated soil conditions 19 months after the application of oil palm empty fruit bunch (EFB) biochar.

Research Design and Sampling

This study employed a quantitative descriptive approach using a field survey and purposive sampling. No additional biochar was applied during the study. Soil samples were collected from areas previously treated with EFB biochar, including locations beneath two dominant cover crop species, *Nephrolepis biserrata* and *Cyperus rotundus*. These species were selected based on their predominance in the study area.

Undisturbed soil samples were collected using soil sampling rings at a depth of 15–20 cm to preserve soil structure for physical analysis. Sampling locations were determined based on the presence of the respective cover crop species within the previously biochar-treated area. Field observations also documented site conditions, vegetation cover, and the visible presence of residual biochar. Secondary data were obtained from the company and previous research records, including biochar application history and relevant plantation information.

Soil Physical Property Analysis

The analyzed parameters included bulk density (g cm^{-3}), particle density (g cm^{-3}), total porosity (%), soil permeability (cm h^{-1}), soil moisture content (%), and soil texture, expressed as sand, silt, and clay fractions (%).

Bulk density was determined from the oven-dried soil mass relative to the sampling ring volume after oven-drying at 105 °C for 24 h. Particle density was determined using a pycnometer-based procedure. Total porosity was calculated from bulk density and particle density. Soil permeability was measured using the constant-head or falling-head method, as appropriate for the soil characteristics, based on Darcy's law. Soil moisture content was calculated from the

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difference between wet and oven-dried soil mass. Soil texture was determined using the Bouyoucos hydrometer method, and the proportions of sand, silt, and clay were used to classify soil texture according to the USDA textural triangle.

Data Analysis

Laboratory results were tabulated, and mean values were calculated for each soil physical parameter based on the sampled locations associated with each cover crop species. Soil conditions were also evaluated in relation to the observations and secondary data available for the 19-month post-application period. The results were interpreted descriptively to characterize soil physical properties under *N. biserrata* and *C. rotundus*. Given the descriptive design, the findings were used to identify observed differences rather than to establish statistically significant causal effects.

RESULTS AND DISCUSSION

Laboratory Analysis of Soil Physical Properties in the Palm Circle

The previous observations and laboratory analyses were conducted eight months after the application of oil palm empty fruit bunch (EFB) biochar. The results of the soil physical property analysis at eight months after EFB biochar application, as reported by Alfazar (2025), are presented in Table 1.

Table 1. Soil Physical Properties at 8 Months after Oil Palm Empty Fruit Bunch (EFB) Biochar Application

Parameter	Blok L	Blok N
Bulk density (g/cm^3)	1,12	1,04
Particle density (g/cm^3)	2,05	2,38
Porositas (%)	57,74	60,75
Permeabilitas (cm/jam)	5,21	3,79
Kadar Air Tanah (%)	39,26	49,48
Tekstur (Pasir) (%)	54	62
Tekstur (Debu) (%)	31	23
Tekstur (Liat) (%)	14	14

The results in Table 1 indicate that, eight months after oil palm empty fruit bunch (EFB) biochar application, both blocks exhibited relatively low bulk density (1.12 and 1.04 g cm^{-3}) and high porosity (57.74% and 60.75%). These findings are consistent with Rauf et al. (2020), who

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reported that biochar application reduced bulk density and increased soil porosity. Permeability was higher in Block L (5.21 cm h^{-1}) than in Block N (3.79 cm h^{-1}), whereas soil moisture content was higher in Block N (49.48%) than in Block L (39.26%). This is consistent with findings that EFB biochar can improve soil water availability (Rauf et al., 2020). Both blocks were dominated by sand fractions (54% and 62%), with a clay fraction of 14%, and were classified as sandy loam. Overall, EFB biochar may improve soil physical conditions through its porous structure, supporting soil moisture retention and root development (Tarigan et al., 2019).

Soil physical properties were reassessed 19 months after biochar application to evaluate conditions over a longer post-application period. The results of the laboratory analyses at 19 months are presented in Table 2.

Table 2. Soil Physical Properties at 19 Months after Oil Palm Empty Fruit Bunch (EFB) Biochar Application

Parameter	Blok L	Blok N
Bulk density (g/cm^3)	1,05	1,04
Particle density (g/cm^3)	2,75	2,60
Porositas (%)	61,82	60,00
Permeabilitas (cm/jam)	5,07	5,15
Kadar Air Tanah (%)	9,26	10,11
Tekstur (Pasir) (%)	32	50
Tekstur (Debu) (%)	40	32
Tekstur (Liat) (%)	28	18

Source: Soil Analysis Results, 2026.

Table 2 shows that, 19 months after EFB biochar application, both blocks had relatively low bulk density (1.05 and 1.04 g cm^{-3}) and high porosity (61.82% and 60.00%). Particle density was higher in Block L (2.75 g cm^{-3}) than in Block N (2.60 g cm^{-3}), while soil permeability was comparable at 5.07 and 5.15 cm h^{-1}, respectively. However, soil moisture content was low in both blocks (9.26% and 10.11%). Soil texture differed between Block L (32% sand, 40% silt, and 28% clay; clay loam) and Block N (50% sand, 32% silt, and 18% clay; sandy loam), potentially contributing to differences in water retention. These results characterize soil physical conditions 19 months after biochar application and provide a basis for evaluating soil management practices in oil palm plantations.

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Analysis of the Relationship Between Cover Crop Presence and Soil Physical Properties Following Oil Palm Empty Fruit Bunch (EFB) Biochar Application

Cover crops in oil palm plantations contribute to soil physical properties through biomass input, root penetration, and organic matter decomposition. *Nephrolepis biserrata*, a shade-tolerant species commonly found in oil palm plantations, has potential as a cover crop and can increase soil carbon stocks and organic matter, although the magnitude of these effects varies among vegetation types (Ariyanti *et al*., 2016). Differences in cover crop characteristics may therefore influence soil physical conditions following long-term biochar application. Accordingly, soil physical properties were evaluated 19 months after oil palm empty fruit bunch (EFB) biochar application to assess variations associated with different cover crop types. The results are presented in Table 3.

Table 3. Analysis of Soil Physical Properties Based on Cover Crop Type

Parameter	D1	D2
Bulk density (g/cm^3)	1,36	1,26
Particle density (g/cm^3)	2,45	2,58
Porositas (%)	55,92	60,08
Permeabilitas (cm/jam)	1,67	1,17
Kadar Air Tanah (%)	46,77	49.06
Tekstur (Pasir) (%)	50	58
Tekstur (Debu) (%)	14	16
Tekstur (Liat) (%)	36	26

Source: Soil Analysis Results, 2026.

Note: D1 = *Cyperus rotundus*; D2 = *Nephrolepis biserrata*.

DISCUSSION

Bulk density is an important indicator of soil compaction and influences porosity, aeration, water movement, and root development. Biochar can reduce bulk density because of its porous structure and contribution to soil aggregation (Premalatha et al., 2023; Muklis et al., 2023). Previous studies reported reductions of 3–31% following biochar application, with a 12% decrease in bulk density and a 12% increase in porosity after applying 20 t ha^{-1} of biochar to silt loam soil (Tokova et al., 2020). However, the magnitude of these effects depends on application rate, soil texture, and field duration. Jiang et al. (2025) reported that biochar effects on bulk density tend to diminish over time, although some benefits persist beyond three years, while Blanco-Canqui

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(2017) noted that reductions may be greater in coarse-textured than in fine-textured soils.

At eight months, bulk density was 1.12 g cm^{-3} in Block L and 1.04 g cm^{-3} in Block N (Alfazar, 2025). At 19 months, it decreased to 1.05 g cm^{-3} in Block L but remained unchanged in Block N (1.04 g cm^{-3}). The decrease in Block L indicates a change in soil physical condition consistent with the reported effects of biochar on bulk density and porosity (Premalatha et al., 2023; Tokova et al., 2020). Nevertheless, the stability of Block N suggests that changes were not uniform between blocks. Both blocks had relatively low bulk density values, which are generally favorable for root growth and soil aeration. Overall, the results indicate that bulk density remained low 19 months after biochar application, although the descriptive design does not establish that biochar alone caused the observed changes.

Particle density reflects the density of soil solids and is influenced by the relative proportions of mineral and organic constituents. Biochar may affect particle density because its density differs from that of mineral soil; however, evidence regarding this response remains limited (Blanco-Canqui, 2017; Zhu et al., 2025). Mukhlis et al. (2023) also identified particle density as an important soil property, despite its limited inclusion in routine soil characterization.

Particle density increased from 2.05 to 2.75 g cm^{-3} in Block L and from 2.38 to 2.60 g cm^{-3} in Block N between the eight- and 19-month observations. These values suggest differences in the composition or characteristics of soil solids over the observation period. Mineral fractions generally have higher particle density (approximately 2.66–2.76 g cm^{-3}) than organic matter (1.27–1.43 g cm^{-3}) (Ruehlmann, 2020). Similarly, Robinson et al. (2022) used reference values of 2.7 g cm^{-3} for mineral particles and 1.4 g cm^{-3} for organic matter in a conservative mixing model. The higher particle density observed at 19 months may therefore reflect differences in soil composition, organic matter decomposition, or spatial variability. However, these mechanisms were not directly measured, and the changes cannot be attributed solely to biochar application.

Soil porosity determines the volume of pore space available for water storage, aeration, and root penetration. Biochar may increase porosity through its internal pore structure and its contribution to soil aggregation (Premalatha et al., 2023). Tokova et al. (2020) reported a 12% increase in porosity following biochar application at 20 t ha^{-1}, while Blanco-Canqui (2017) reported increases of approximately 14–64%, depending on soil texture and biochar characteristics. Nevertheless, porosity responses can change over time because of soil consolidation, wetting–drying cycles, and biochar ageing. Jiang et al. (2025) found that the effects of biochar on total porosity generally peaked around the second year and subsequently declined, although positive effects could persist relative to untreated soil. Zhu et al. (2025) further emphasized that responses

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depend on soil texture and biochar particle size.

Porosity increased from 57.74% to 61.82% in Block L but decreased slightly from 60.75% to 60.00% in Block N between eight and 19 months. These values fall within the porous soil category reported by Alfazar (2025). The increase in Block L is consistent with the potential of biochar to improve pore space, whereas the small decrease in Block N suggests relatively stable porosity during the observation period. Both blocks maintained porosity values generally considered favorable for soil aeration, water movement, and root development. These findings indicate different temporal patterns between blocks rather than a uniform response to biochar.

Soil permeability describes the capacity of water to move through soil pores and is influenced by pore continuity, aggregation, and soil structure. Biochar may improve water movement by modifying soil aggregation and pore structure. Premalatha et al. (2023) reported an increase in saturated hydraulic conductivity from 2.70 to 13.4 cm h^{-1} following biochar addition. However, permeability may change over time due to pore clogging, particle migration, and structural alteration. Jiang et al. (2025) associated changes in saturated hydraulic conductivity with biochar movement into deeper soil layers and pore clogging, while Barnes et al. (2014) demonstrated that repeated flushing can alter pore structure through swelling and particle segregation.

Between eight and 19 months, permeability in Block L reportedly decreased from 51.21 to 5.07 cm h^{-1}, whereas Block N increased from 3.79 to 5.15 cm h^{-1}. The contrasting patterns suggest that water transmission changed differently between blocks. Structural stabilization and changes in pore-size distribution may help explain the decrease in Block L, whereas improved pore continuity may have contributed to the increase in Block N. These mechanisms remain possible explanations because pore-size distribution and structural changes were not directly assessed. At 19 months, permeability values were similar between blocks (5.07 and 5.15 cm h^{-1}), indicating comparable measured water-transmission rates at the time of sampling. These findings are consistent with the view that the effects of biochar on soil hydraulic properties can evolve with field ageing (Barnes et al., 2014; Jiang et al., 2025).

Soil moisture content reflects the balance between water input, storage, and loss. Biochar can improve water retention through its specific surface area, surface functional groups, and internal pore structure. Wei et al. (2023) reported greater biochar effects on field capacity and available water capacity in coarse-textured soils than in medium- and fine-textured soils. Blanco-Canqui (2017) also reported increases of 4–130% in available soil water, depending on biochar and soil characteristics. However, water-retention effects may vary with rainfall, evaporation,

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plant water uptake, and biochar ageing. Wang et al. (2019) found that biochar pores may become progressively occupied by organic and mineral materials after application, while Jiang et al. (2025) reported that biochar effects on available water capacity peaked around the second year before declining.

Soil moisture content decreased from 39.26% to 9.26% in Block L and from 49.48% to 10.11% in Block N between eight and 19 months. The lower values at 19 months coincided with lower rainfall: 91 mm in June 2025 compared with 39 mm in June 2026. This difference may have contributed to the observed decline, although rainfall alone cannot be confirmed as the cause. Satriawan et al. (2023) reported that cover crops can positively affect soil moisture, particularly during dry periods and months with moderate rainfall. Water uptake by oil palm may also contribute to soil-water depletion; Safitri et al. (2019) estimated actual root water uptake at 3.07–3.73 mm day^{-1}, depending on palm age and soil type. Although biochar can improve water retention through changes in surface properties and pore structure (Wei et al., 2023), the low moisture values at 19 months indicate that soil water content was also influenced by environmental conditions and plant water use. Block N retained slightly more moisture than Block L (10.11% versus 9.26%).

Soil texture is determined by the relative proportions of sand, silt, and clay and is generally more stable than other soil physical properties. Although biochar may interact with soil minerals and undergo physical disintegration, changes in particle-size fractions should be interpreted cautiously. Putri et al. (2026) reported changes in soil properties and organic matter following the application of macro-biochar to Psamment soil. Premalatha et al. (2023) also found that erosion responses varied with biochar application rate and particle size, while Wang et al. (2021) described the gradual reduction in biochar particle size during natural decomposition. These findings indicate that biochar characteristics and soil processes may affect soil-particle dynamics, although they do not establish that biochar directly changes the inherent texture of field soil.

The sand fraction decreased from 54% to 32% in Block L and from 62% to 50% in Block N between eight and 19 months. Because soil texture is relatively stable, these differences are unlikely to demonstrate a direct biochar-induced change (Usowicz & Lipiec, 2021). Soil texture also influences biochar responses, with sandy soils generally responding differently from clay-rich soils (Blanco-Canqui, 2017). Spatial heterogeneity and sampling or laboratory variation may have contributed to the observed differences, as soil properties can vary with topography and agroclimatic conditions (Taye et al., 2018). At 19 months, Block N had a higher sand fraction than Block L, which may be associated with greater drainage and lower water retention. Sandy soils

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generally exhibit high hydraulic conductivity but limited water retention (Gluba et al., 2021; Ibrahimi & Alghamdi, 2022). Therefore, the observed changes are more appropriately interpreted as differences between sampling periods and locations rather than direct evidence of biochar-induced textural transformation.

The silt fraction increased from 31% to 40% in Block L and from 23% to 32% in Block N. Biochar disintegration may generate finer particles, with the extent of disintegration influenced by ash content and aromaticity (Sigmund et al., 2023). Dissolved biochar fractions may also form organo-mineral complexes that contribute to biochar stabilization in soil (Yan et al., 2021). In addition, soil fauna can influence particle distribution and mineral transformations through bioturbation and organic matter processing (Angst et al., 2024). Nevertheless, the increase in silt fraction cannot be directly attributed to biochar because soil texture is relatively stable over short periods (Usowicz & Lipiec, 2021). Differences in sampling locations, soil heterogeneity, and laboratory analysis may also explain the observed variation. At 19 months, Block L had a higher silt fraction than Block N (40% versus 32%). Silt-rich soils may retain more plant-available water than coarse-textured soils; silt loam soils have been reported to provide relatively high available-water storage while maintaining better aeration than soils with high clay contents (Amsili et al., 2021).

The clay fraction increased from 14% to 28% in Block L and from 14% to 18% in Block N. Biochar may interact with fine soil particles through organo-mineral complex formation (Yang et al., 2021), while clay distribution in topsoil can also be affected by natural particle translocation through eluviation and bioturbation (Sauzet et al., 2023). However, soil texture is generally stable over short periods, so the observed changes should not be interpreted as direct evidence of biochar-induced changes (Usowicz & Lipiec, 2021). Sampling variability, soil heterogeneity, and laboratory procedures may have contributed to the differences.

At 19 months, Block L had a higher clay fraction than Block N (28% versus 18%). Clay-rich soils can retain nutrients through cation exchange and interactions with soil colloids (Ciric et al., 2023), but higher fine-particle contents can also alter pore-size distribution and restrict drainage when soil structure is unfavorable. Wang et al. (2023) reported that changes in the proportions of sand and clay significantly affect soil pore-size distribution and water-retention characteristics. Yang et al. (2021) further highlighted the potential interactions between biochar-derived fractions and soil minerals. Overall, the observed differences in clay content may reflect variation in soil characteristics between blocks and sampling periods; further replicated sampling would be required to determine their causes.

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Different cover crop species were associated with distinct soil physical properties in oil palm plantations following oil palm empty fruit bunch (EFB) biochar incubation. The *Nephrolepis biserrata* plot (D2) exhibited a lower bulk density (1.26 g/cm³) than the *Cyperus rotundus* plot (D1; 1.36 g/cm³), accompanied by higher total porosity (60.08% vs. 55.92%) and soil moisture content (49.06% vs. 46.77%). These findings are consistent with Baru Bara and Yosephine (2026), who reported substantially lower bulk density in areas with cover vegetation than in areas without cover crops. The rhizome and fibrous root systems of ferns may contribute to pore formation and continuous organic matter input. Furthermore, *Nephrolepis biserrata* can help maintain soil moisture through organic matter accumulation and reduced excessive evapotranspiration (Satriawan *et al*., 2021).

Both cover crop plots had the same soil textural classification, sandy clay loam. The D1 plot contained 50% sand, 14% silt, and 36% clay, whereas D2 contained 58% sand, 16% silt, and 26% clay. These results suggest that soil permeability is not determined solely by texture but is also influenced by pore structure and root activity. Changes in soil porosity and hydromechanical properties associated with root activity may vary according to plant genotype and species, measurement scale, and soil texture (Marin *et al*., 2022). The particle density of D2 (2.58 g/cm³) was also higher than that of D1 (2.45 g/cm³), indicating differences in soil composition between the two cover crop plots.

Overall, the results indicate that cover crop type is associated with variations in soil physical properties following EFB biochar application. *Nephrolepis biserrata* tended to be associated with lower bulk density, greater total porosity, and higher soil moisture content, whereas *Cyperus rotundus* exhibited relatively higher bulk density. These differences suggest that cover crop characteristics may influence soil physical conditions, although the observed differences alone do not establish a causal effect of cover crop type.

CONCLUSION

The findings indicated that 19 months after oil palm empty fruit bunch (EFB) biochar application, soil physical properties varied across blocks and cover crop types. Soil moisture content declined by approximately 76–79% between months 8 and 19, while *Nephrolepis biserrata* was associated with lower bulk density, higher porosity, and greater soil moisture content than *Cyperus rotundus*. Permeability also differed between cover crop plots, highlighting the role of soil pore structure and root activity. These results suggest that integrating EFB biochar with suitable cover crops may support soil physical quality in oil palm plantations. Further research

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should investigate different biochar application rates, cover crop species and densities, and long-term changes in soil physical, chemical, and biological properties to establish more comprehensive and sustainable land management recommendations.

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