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Study of Physical Properties on Spodosols in Eucalyptus Plantation Area at PT. Wirakarya Sakti

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ABSTRACT

Spodosols are widely distributed across Indonesia, covering approximately 2.16 million hectares, presenting significant potential for utilization as industrial forest plantation land, heavily reliant on its physical properties. The selection of the type of HTI plants to be cultivated depends on their adaptability. Eucalyptus is one plant known for its good adaptability to less fertile soil. This research was conducted on the land of PT. Wirakarya Sakti for 3 months, from February to April 2023, located in District 1, Betara District, Tanjung Jabung Barat Regency, Jambi Province. The aim of the research is to investigate the impact of land use planted with Eucalyptus compared to conservation forest on the physical properties of the soil. The research utilized a field survey method covering an area of approximately 326.4 hectares and the determination of points and sample collection using the stratified random sampling method. Samples were taken at locations including the conservation forest and land planted with Eucalyptus aged 1, 2, and 3 years, with 6 samples taken at depths of 0-30 cm and 30-60 cm, totaling 48 samples. Observed variables included soil texture, organic matter, bulk density, total pore space, moisture content, and permeability. The research results indicate that the physical properties of Spodosol soil include high soil volume weight due to the presence of an albic horizon in the upper layer and a spodic horizon in the lower layer, as well as high organic carbon content in the spodic horizon

Key words: Eucalyptus; Physical Properties; Spodosol

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INTRODUCTION

The transformation of forests into grazing and agricultural lands is one of the most concerning issues in environmental degradation and global climate change. Changes in human land use behavior have altered the characteristics of the Earth's surface, leading to changes in the physical-chemical properties of soil, soil fertility, soil erosion sensitivity, and soil moisture content. Land use changes such as deforestation, conversion of grazing lands to agricultural lands, and cultivation are known to result in changes in the physical-chemical and biological properties of soil (Evrendilek, et al., 2004). The impact of these changes and their magnitude depend on land cover and land management. Changes in land use and agricultural practices, especially cultivation of deforested land, can rapidly degrade soil quality. Severe soil quality degradation can lead to permanent land productivity decline. The transformation of one land use system to another and different management practices can affect soil structure, soil organic carbon, and other nutrient reserves (Yeshanew, et al., 2004). The type of land use affects soil physicochemical properties and provides an opportunity to evaluate the sustainability of land use systems and thus the underlying soil degradation processes associated with land use (Woldeamlak and Stroosnijder, 2003). However, information on the effects of land use change on soil physicochemical properties is crucial for providing recommendations for the optimal and sustainable utilization of land resources.

Spodosols are widely distributed in cold, temperate, or wet climates. The widest distribution is found in Russia, Northern Europe, and Canada (McKeague et al., 1983). Spodosols occupy about 4% of the world's non-glacial land surface (Balasubramanian, 2017). In Indonesia, the total area of Spodosols is estimated at 2.16 million hectares or 1.1% of Indonesia's land area (Subagjo et al., 2004). Despite covering only 1.1% of Indonesia's land area, Spodosols are important to understand because they are problematic for both agricultural and forest lands. Spodosols are acidic soils characterized by the accumulation of humus below the surface complexed with Al and Fe. These soils typically have a bright albic or E horizon covering reddish-brown spodic horizons. There is a common belief that Spodosols have sandy texture (Hartemink, 2017). Soil chemical properties are characterized by acidic soil reaction and poor nutrient content. Coarse texture results in low nutrient and water retention capacity, making the soil prone to drought. Additionally, the presence of hardpans (fragipan or duripan) at varying depths can hinder plant growth. Based on the unfavorable characteristics of Spodosols, some experts argue that they should not be used for agricultural land due to environmental reasons and their low potential for agriculture or forestry, while others argue that they can still be selectively used for agriculture with high-input management. Spodosol has two significant limiting factors that need attention: the depth of the spodic horizon and the sandy soil texture. The depth of the spodic layer affects the ease with which roots can penetrate the soil, while the sandy texture reduces the soil's ability to retain water and increases the likelihood of nutrient leaching. Other limiting factors that can potentially hinder plant growth include poor drainage and soil acidity (Wiratmoko et al., 2007; Kasno and Subarja, 2010). Additionally, Spodosol has a bulk density ranging between 1.32 g/cm^3 and 1.63 g/cm^3, with permeability between 12.01 cm/hour and 22.44 cm/hour (Surianto, 2015).

Soils with sandy texture are not widely utilized for plant cultivation, especially in agricultural activities, because they are classified as suboptimal land, generally nutrient-poor. This condition renders sandy soil infertile, with low nutrient content, thus affecting plant growth and production. As explained by Dedik and Diah in Liwi (2021), sandy soil is considered less favorable due to its very low fertility and nutrient deficiency. Sandy soil undergoes intensive podsolization processes, making it very nutrient-poor and less suitable for food crops, but it can be managed for industrial plantation forests.

The poor physical properties of spodosols mean that the selection of plantation tree species highly depends on their adaptability. According to Leksono (1996), Eucalyptus trees have good adaptability to less fertile soils. However, under such conditions, the growth of Eucalyptus is not optimal and is characterized by relatively low plant productivity. This is because there is a close relationship between soil characteristics and plant productivity improvement (Goncalves et al., 2004; Bristow et al., 2005; Bristow et al., 2006; Dombro, 2010). Eucalyptus production in Indonesia from 2018 to 2020 has continued to increase. In 2018, Eucalyptus production was 7,953.573 tons, in 2019 it was 8,689.309 tons, and in 2020 it was 13,350.735 tons. This productivity makes Eucalyptus forestry plants highly demanded (BPS, 2020).

PT. Wirakarya Sakti is one of the largest companies in the forestry industry, originating from the Sinarmas Forestry Division group as a supplier of raw materials for pulp and paper industries within the PT. Lontar Papyrus Pulp and Paper Industry group, which is also located in Jambi Province. With an area of ±290,378 Ha in 2021, particularly in district 1 covering an area of 48,588 Ha located in West Tanjung Jabung Regency (WKS, 2021).

MATERIAL AND METHOD

This research was conducted on Spodosol soil in the HTI land of PT. Wirakarya Sakti, District 1, Betara Subdistrict, Tanjung Jabung Barat Regency, Jambi Province. This research was conducted from February 2023 to April 2023. The materials and tools used in the research were intact soil samples taken using a soil ring from the conservation forest, soil samples from 1, 2, and 3-year-old Eucalyptus plants, munshell book, soil rings, knife/cutter, hoe, mobile phone, plastic bags, ring covers, rubber, labels, writing tools, and other equipment needed for soil analysis in the laboratory.

The research was conducted using a survey method with a working area of approximately 326.4 ha. The determination of points and sample collection was carried out using soil rings with stratified random sampling method. Observation of soil morphological properties in the field was conducted according to the guidelines of Soil Survey (Soil Survey Staff, 1991), and soil classification followed the Soil Taxonomy System (Soil Survey Staff, 1918). Soil sampling was carried out at four locations: in the conservation forest as control and Eucalyptus land aged 1, 2, and 3 years, each with 6 samples with strata of depths 0 – 30 cm and 30 – 60 cm. Four minipit were selected for this study from four locations in each land use type including conservation forest land (figure 1.a), land planted with 1-year-old ecalyptus plants (figure 1.b), 2-year-old ecalyptus plants (figure 1.c), and 3-year-old eucalyptus plants (figure 1.d). Soil samples were taken totaling 48 disturbed soil samples (using soil augers) and undisturbed soil samples (using stainless steel rings) taken from soil depths of 0-30 cm and 30-60 cm from 4 different planting locations (conservation forest land, land planted with 1-year-old ecalyptus plants, 2-year-old plants, and 3-year-old plants).

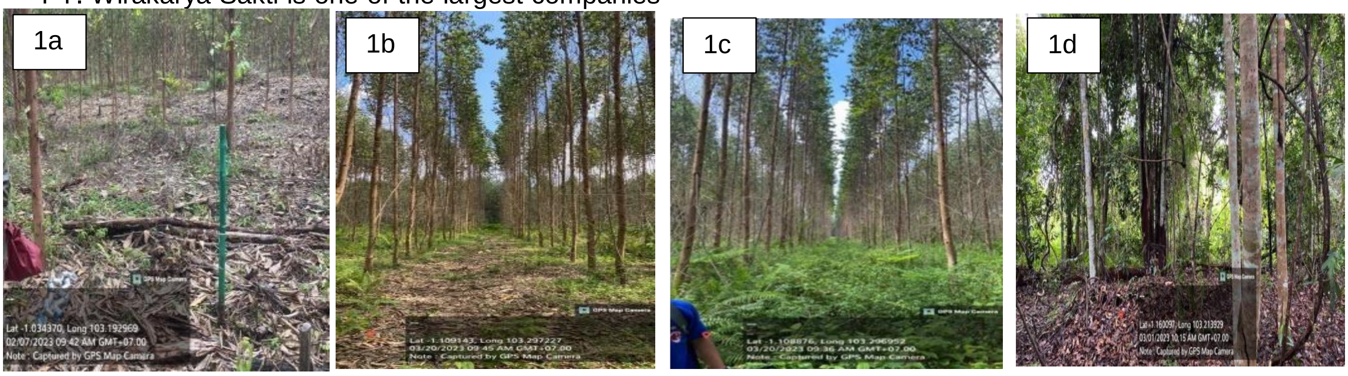

Figure 1a. Land planted with 1-year-old eucalyptus plants; 1b. Land planted with 2-year-old eucalyptus plants; 1c. Land planted with 3-year-old eucalyptus plants; 1d. land planted with conservation forests.

Laboratory analysis methods for soil samples include determining soil texture using the pipette method. This involves the destruction of organic matter and the dispersion of sodium hexametaphosphate into the soil. The USDA classification system is used to identify soil texture classes. Soil bulk volume is analyzed after drying in an oven at 105°C for 24 hours. Total soil porosity is calculated using the specific gravity and particle density values (assumed to be 2.65 $g\ cm^{-3}$). Soil water content is determined using the gravimetric method. Soil organic carbon (SOC content) is determined using the Walkley-Black $K_2Cr_2O_7$ oxidation method (Nelson et al., 1996).

RESULT AND DISCUSSION

Mini Soil Pits in Land Planted with Eucalyptus and Forest Land Conservation

Morphologically, Spodosols are easily recognizable in the field due to their coarse texture (sandy to sandy loam, Table 1) and the presence of characteristic horizons such as the eluviation horizon or albic E horizon which is light/pale in color, and the illuviation horizon or spodic B horizon below it which is dark. Figures 2a, 2b, 2c, and 2d show Spodosol mini-pits planted with 1-year-old, 2-year-old, 3-year-old Eucalyptus plants, and those planted with conservation forest plants. The mini-pit of land planted with 1-year-old Eucalyptus plants shows horizons consisting of an Ap horizon at a depth of 0-10 cm, an E-albic horizon at a depth of 10-30 cm, and a B-spodic horizon at a depth of 30-60 cm (Figure 2a) and Figure 2b, the mini-pit on land planted with 2-year-old Eucalyptus plants shows horizons consisting of Ap at a depth of 0-30 cm, E-albic horizon at a depth of 30-40 cm, and at a depth of 40-60 cm, there is a B-spodic horizon. Subsequently, the mini-pit on land planted with 3-year-old Eucalyptus plants shows an Ap horizon at a depth of 0-27 cm, an E-albic horizon at a depth of 27-50 cm, and a B-spodic horizon at a depth of 50-60 cm (Figure 2c), and the mini-pit of land planted with conservation forest plants consists of an Ap horizon at a depth of 0-20 cm, an E-albic horizon at a depth of 21-30 cm, and a B-spodic horizon at a depth of 31-60 cm (Figure 2d). Typical Spodosols are characterized by four main horizons: (i) the surface organic horizon which is dark or A horizon, (ii) the eluvial horizon or albic E horizon which is pale in color, (iii) the illuvial horizon or spodic B horizon which is dark red, brown, or black enriched with amorphous materials, and (iv) a sandy C horizon below it (McKeague et al., 1983).), characterized by a high value (≥5) and low hue (≤2) (Prasetyo et al., 2006).

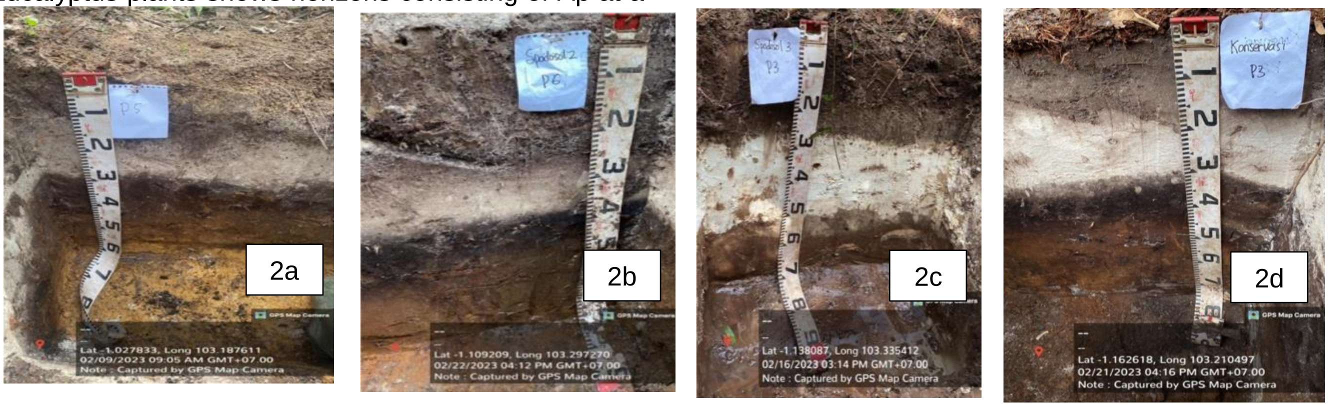

Figure 2.a. minipit land planted with 1-year-old eucalyptus plants; 2b. minipit land planted with 2-year-old eucalyptus plants; 2c. minipit land planted with 3-year-old eucalyptus plants; 2d. minipit of land planted with conservation forests

The color of the A horizon or surface horizon, which is dark (very dark brown to black), indicates richness in organic matter. The accumulation of organic matter in the A horizon is the result of litter deposition supported by microbial activity during decomposition. The thickness of the A horizon varies widely from a few centimeters to several tens of centimeters, depending on the vegetation conditions above the surface in the mini-pit (Figures 2a, b, c, and d). The albic E horizon is an eluvial horizon that has undergone intensive leaching, resulting in a deficiency of exchangeable bases, organic matter, iron, and aluminum. This horizon is light or pale in color (light gray to white).

Mini-pits on land planted with one-year-old and two-year-old Eucalyptus plants show small and few fine roots, while large root quantities are absent. On land planted with three-year-old Eucalyptus plants, the mini-pits show large and medium roots in small quantities. Furthermore, on land planted with conservation forest plants, the mini-pits show small quantities of large roots and medium and small roots in large quantities.

The soil texture analysis includes two depths, namely 0-30 cm and 30-60 cm. Table 1 shows the sandy texture class in the land planted with 1-year-old and 2-year-old Eucalyptus plants in both layers 0-30 cm and 30-60 cm. Meanwhile, the soil planted with 3-year-old Eucalyptus plants and the conservation forest plants exhibit a sandy loam texture class in both layers 0-30 cm and 30-60 cm.

Table 1. Average Soil Texture Analysis Results of Spodosol planted with Eucalyptus and Conservation Forest Plants

Land Use	Dept	Clay	Sand	Dust	Texture Class
Eucalyptus 1 year	0 – 30 cm	2,56	88,74	8,70	Sand
	30 – 60 cm	2,60	88,49	7,91	Sand
Eucalyptus 2 year	0 – 30 cm	2,85	88,83	8,32	Sand
	30 – 60 cm	2,09	89,06	8,86	Sand
Eucalyptus 3 year	0 – 30 cm	3,81	81,24	14,94	Sandy Loam
	32 – 60 cm	3,65	9,69	16,64	Sandy Loam
Conservation Forest	0 – 30 cm	3,09	84,62	12,29	Sandy Loam
	30 – 60 cm	3,27	83,69	13,04	Sandy Loam

C-organic, Bulk Density, Total Pore Space, and Water Content

The average results of soil texture analysis, organic carbon (C-organic) content, bulk density (BD), total pore space (TPS), and moisture content (Table 1) indicate that the research site has organic carbon values ranging from 1.44% to 2.26% with low to moderate criteria in the 0-30 cm layer and 2.13% to 3.04% with moderate to high criteria (BPT, 2009) in the 30-60 cm layer. The organic carbon content at one year is 1.44% (0-30 cm), lower compared to other ages because the 0-30 cm depth is taken from the albic E horizon, resulting in very low organic matter content due to leaching, which accumulates in the B-spodic horizon. Additionally, the small size of the plants contributes to the lower organic matter contribution. At two and three years of age, there is an increase in organic carbon values in the 0-30 cm depth. Mini-pits at two and three years of age show the presence of an Ap horizon, with topsoil containing litter from leaves and branches, contributing to higher organic matter content. This aligns with Supangat (2013), who stated that older Eucalyptus trees show an increase in soil organic matter.

The organic carbon content at depths of 30–60 cm ranges from 2.13% to 3.04%, showing a higher percentage compared to the 0-30 cm depth, which ranges from 1.44% to 2.04%. The high organic matter value in the A horizon decreases in the albic E horizon and increases again in the spodic B horizon. The low organic matter value in the albic horizon is due to illuviation processes occurring in the Bhs horizon. This horizon forms due to illuviation processes, where percolating water carries dissolved organic matter and other minerals through the upper soil layers. During this process, organic matter is carried deeper into the soil. Upon reaching the lower layers, organic matter deposits occur, leading to increased organic matter in the lower layers and depletion in the upper layers (Suharta and Prasetyo, 2009). The distribution of organic matter content according to soil depth shows accumulation in the surface layer, decreasing to the albic E horizon due to leaching, and increasing into the spodic B horizon based on accumulation (Table 1).

Spodosol soil has low to high organic carbon content. Darker soil surface color (indicating uneroded organic matter) implies higher organic carbon content, while lighter surface color (where the spodic horizon emerges) indicates lower organic carbon content. Therefore, leaching processes occur more rapidly in sandy-textured soils with low organic carbon content. The role of organic carbon is evident in soils planted with three-year-old Eucalyptus trees (greener and healthier compared to others). Based on changes in nutrient elements, there is a decrease in organic carbon content from the AP and E1 horizons due to intensive leaching, resulting in low soil organic matter content, low clay, Fe, and Al content, but low quartz content, and high resistant minerals, resulting in a lighter color (Balittanah, 2004). Meanwhile, organic carbon content increases from E2 and continues into B2 until it remains stable in B2. This can be observed in the spodosol soil mini-pits in the research area (Figures 2a, b, c, and d).

Conservation forests have lower organic carbon content in the Ap layer compared to land planted with 2- and 3-year-old Eucalyptus plants. At a depth of 0-30 cm, the organic carbon content is 2.04%, while at a depth of 30-60 cm, it is 3.04%. This may be due to the presence of the albic E horizon at a depth of 20-30 cm, which contains little organic matter. Meanwhile, at a depth of 30-60 cm, there is the presence of the spodic B horizon rich in humus, resulting in higher organic matter content. This aligns with Surianto's research (2015), which found high organic matter content at a depth of 60-70 cm in the Bhs horizon. The accumulation of organic matter along with Al and Fe as a result of illuviation in the spodic horizon leads to higher organic matter content in deeper layers. Unlike the three-year-old Eucalyptus, which experiences a decrease in organic carbon content at a depth of 30-60 cm, as seen in the soil mini-pit planted with three-year-old Eucalyptus, which shows the presence of the albic E horizon at a depth of 27-50 cm (Figure 2c). The albic E horizon itself has little or no organic matter or has undergone leaching, resulting in the loss of organic matter. Prasetyo et al. (2006) stated that in Spodosol soil in Kutai District, East Kalimantan, high organic carbon levels are found in the A horizon, decrease again in the albic E horizon, and increase again in the lower horizon or B-spodic. The low organic carbon in the upper layer (Albic) is due to eluviation processes, where Spodosol has a specific characteristic called the Bhs or eluvial horizon. This horizon is formed due to eluviation processes, where percolating water through the upper soil layers carries dissolved organic matter and mineral particles. During percolation, dissolved organic matter can be deposited in deeper layers, as when this water reaches the layers below, the deposition of this organic matter occurs, leading to an increase in organic carbon content in the lower layers and the upper layers becoming poor in organic matter.

Table 2. Results of Analysis of Organic Carbon Content, Bulk Volume, Total Pore Space, and Moisture Content of Spodosol planted with Eucalyptus and Conservation Forest Plants

Land	C-organic (%)		BV(g cm^{-3})		TRP (%)		KA (%)	
Use	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
A	1.44	2.13	1.35	1.42	44.48	39.47	23.98	26.81
B	2.21	2.65	1.07	1.27	49.02	41.39	26.06	26.90
C	2,26	2.12	1.16	1.35	49.79	43.23	27.63	26.44
D	2.04	3.04	1.18	1.35	46.70	38.50	36.92	26.03

Explanation: A. Spodosol planted with 1-year-old Eucalyptus plants; B. Spodosol planted with 2-year-old Eucalyptus plants; C. Spodosol planted with 3-year-old Eucalyptus plants; D. Spodosol planted with conservation forest plants.

According to Table 2, from the soil bulk density analysis, it is found that at one year of age, the soil bulk density at depths of 0-30 cm is 1.35 g/cm³, and at depths of 30-60 cm, it is 1.42 g/cm³, tending to be denser. At two years of age, the soil bulk density tends to decrease by 1.07 g/cm³ at depths of 0-30 cm and 1.27 g/cm³ at depths of 30-60 cm. Meanwhile, at three years of age, the soil bulk density is 1.16 g/cm³ at depths of 0-30 cm and increases to 1.35 g/cm³ at depths of 30-60 cm. It can also be seen that at one year of age, the soil bulk density is higher compared to two and three years of age. The bulk density at two and three years of age is lower at depths of 0-30 cm compared to one year of age. The decrease in bulk density is influenced by Eucalyptus root growth. Plants growing in the upper layer have roots that creep and cause changes in soil structure. Plant roots help push soil particles, create soil pores, and reduce soil density. At a depth of 30-60 cm, there is an increase in bulk density at each age. This is because of the spodic layer, which causes the bulk density values in that layer to become dense. The high soil bulk density values are due to leaching processes, where compounds soluble in water such as organic matter are pushed to this layer through eluviation (albic) and illuviation (spodic) processes. Supported by Mookma and Buurman (1982), this process will continue repeatedly. This is what explains the formation of the spodic layer with varying depths. As a result, this lower layer is rich in mineral deposits. These mineral deposits tend to have higher densities, thereby increasing the soil bulk density values. The soil bulk density value in the conservation area is 1.16 g/cm³ at depths of 0-30 cm and increases to 1.35 g/cm³ at depths of 30-60 cm. This is because at a depth of 0-30 cm, there is an albic layer with a higher sand content. Meanwhile, at a depth of 30-60 cm, harpen is found, (a hard layer) that cannot be penetrated by the sampling ring during soil sampling.

The bulk density values at one year of age tend to be denser compared to other ages. The obtained bulk density results correlate with the organic matter content obtained. The decreasing bulk density values at depths of 0-30 cm for one, two, and three-year-old plants indicate an increasing percentage of organic matter content. The impact of land use change on soil physical suitability has been widely recognized, especially when considering the conversion of tropical forests into grazing land or agricultural land (Scheffler et al., 2011). Changes in soil bulk density, penetration resistance, porosity, near-surface hydraulic conductivity (Zimmermann et al., 2006), infiltration, and saturated hydraulic conductivity (Horel et al., 2015) are described as possible consequences of land use change. Similar findings were reported by Celik (2005) that deforestation and subsequent soil management practices resulted in increased surface soil density in the southern highlands of Turkey.

The average results of the analysis of total soil porosity in Spodosols planted with Eucalyptus trees and conservation forests show that the total soil porosity for one-year-old plants has a value of 44.48% at a depth of 0-30 cm and 39.47% at a depth of 30-60 cm. The total soil porosity for two-year-old Eucalyptus trees is 49.02% at a depth of 0-30 cm and 4.39% at a depth of 30-60 cm. Meanwhile, for three-year-old plants, the total porosity is 49.79% at a depth of 0-30 cm and decreases to 43.23% at a depth of 30-60 cm. On the other hand, in the conservation area, the total soil porosity is lower, at 46.70% at a depth of 0-30 cm and 38.50% at a depth of 30-60 cm. The increase in the total soil porosity value, as observed in the age of Eucalyptus trees, correlates with the increase in soil organic matter content and the decrease in soil bulk density. This can be seen in the 0-30 cm depth where the total soil porosity increases at each age, accompanied by an increase in organic matter and bulk density. At three years of age, it has a very high value compared to one and two-year-old plants and conservation land because there is a thick layer of albic E horizon resulting in lower bulk density and increased total soil porosity in this layer, with sufficiently high organic matter content.

Table 2 shows that the average soil moisture content at a depth of 0-30 cm ranges from 23.98% - 36.92%, higher than the layer from 30-60 cm which ranges from 26.81% - 26.03%. It can be observed that each land use has different moisture content. Forests have higher soil moisture content compared to other land uses, at 36.92% at a depth of 0-30 cm and 26.03% at a depth of 60-30 cm. Saribun (2007) explained that forest and Eucalyptus forest land uses are suspected to have high organic matter content. The more organic matter in the soil, the higher the water content at field capacity, due to the increase in medium-sized pores (meso) and the decrease in macro pores, thus increasing water retention, and impacting the increased water availability for plants (Scholes et al., 1994). Organic matter such as leaves, branches, etc., that have not yet decomposed covering the soil surface, serve as soil protectors against the erosive force of falling raindrops. This organic matter inhibits surface water flow, causing it to flow slowly. Decomposed organic matter in forest land and forest has low water retention and nutrient-holding capacity. Furthermore, sandy-textured soils have low water retention capacity. Sandy-textured soils also have low water retention and other organic matter (Baskin, 1998).

The use of Eucalyptus land has a soil moisture content ranging from 23.98% to 27.63%, lower than forests. This happens because Eucalyptus land has undergone soil processing, thus reducing the quality of soil physical properties characterized by low soil porosity. Soil processing affects soil organic matter availability, thus affecting soil moisture content. The organic matter content in cultivated soil does not support the process of water absorption into the soil, making it more susceptible to erosion, thus reducing groundwater availability compared to forest land. The conversion of forests into agricultural land is known to worsen soil physical properties and make the land more vulnerable to erosion because macro-aggregates are disturbed (Baskin, 1998). Soil erosion can alter soil properties by reducing soil depth, altering soil texture, and loss of nutrients and organic matter (Lobe, 2001). Corley and Tinker (2016) stated that soil texture can affect soil's ability to retain water.

Overall, there is an increase in soil moisture content with increasing soil organic matter content (Table 2). Soil bulk density and total soil porosity have changed due to the increase in soil organic matter. Total soil porosity increases and soil density decreases when soil organic matter content is high. Soil with low bulk density and high porosity facilitates water entry into the soil and absorption by soil organic matter, thus increasing soil moisture content (Downie et al., 2009).

Permeability

The average permeability measurements (Table 3) resulted in soil planted with one-year-old eucalyptus trees showing a soil permeability value at a depth of 0-30 cm of 3.69 cm hr-1 and 1.21 cm hr-1 at 30-60 cm, tending to be denser. For two-year-old eucalyptus trees, the permeability value was 23.76 cm hr-1 at a depth of 0-30 cm and 13.03 cm hr-1 at a depth of 30-60 cm. Meanwhile, for three-year-old eucalyptus trees, the permeability value was 15.06 cm hr-1 at a depth of 0-30 cm and 5.69 cm hr-1 at a depth of 30-60 cm. The soil permeability analysis indicates varying permeability results for each land use, with the highest permeability level found in two-year-old eucalyptus land at 23.76 cm hr-1, classified as fast. In contrast, permeability at one year of age was low, ranging from

1.21 cm hr-1 to 3.69 cm hr-1, classified as somewhat slow and moderate. According to several research findings, plant root system growth and development in the soil, including soil macroporosity, impact soil permeability increase (Scholl et al., 2014; Leung et al., 2018).

Table 3. Average Results of Permeability Analysis of Spodosol Planted with Eucalyptus and Conservation Forest Plants

Land Use	Permeability (cm jam^{-1})	
	0-30 cm	30-60 cm
A	3,69	1,21
B	3,76	13,03
C	15,06	5,69
D	10,46	8,29

The obtained permeability values correlate with bulk density values. At one year of age, soil permeability is slower compared to other ages. This is because the dense bulk density values cause the water passage capacity to be slow. Meanwhile, at two and three years of age, permeability ability is moderate to fast in line with the bulk density values obtained. Soil texture is one of the most commonly defined soil properties in determining soil classes (Hartati, et al., 2021). Soils dominated by sand fractions generally have loose structures and good infiltration and permeability capacity (Hidayat, et al., 2019). However, unlike that, spodosols have poor infiltration due to the presence of a hardpan layer (De Oliveira, 2010).

Table 2 shows that the bulk density values at each depth are decreasing, and soil porosity is increasing. Dense soil indicates high bulk density and decreased porosity, which hampers the speed of soil in water passage and plant root development (Lal, 2017). Some soil characteristics affecting soil permeability are bulk density, porosity, soil texture, pore size distribution, and aggregate stability (Haryati, 2014; Zhang et al., 2019).

CONCLUSION

The results of this research can be concluded that the physical properties of the soil layer 0-30 cm of spodosol planted with eucalyptus or conservation forest plants show no significant differences because in the planting of eucalyptus plants, management and the provision of organic materials in the form of compost are also carried out. In the 30-60 cm layer, it shows a high value of soil bulk density due to the presence of an albic horizon in the upper layer and a spodic horizon in the lower layer which has a high density and hardness level as well as a high content of organic matter.

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