Vol. 13, No. 4 (2024): 1101 - 1108
http://dx.doi.org/10.23960/jtep-l.v13i4.1101-1108

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Soil Physical Properties of Oil Palm Plantations in Tidal Areas of Peatland

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Article History:

Received : 14 May 2024
Revised : 18 June 2024
Accepted : 24 June 2024

Keywords:

Loamy sand,
Oil palm,
Peat soil,
Soil color,
Soil texture.

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ABSTRACT

*Oil palm (*Elaeis guineensis *Jacq) is a plant with a higher vegetable oil content than other oil-producing plants, so palm oil is widely used as the main raw material for processed vegetable oil. The increasingly limited land area and the larger land area in Indonesia so that the space for plantation companies to expand the land is increasingly limited, so that the expansion of oil palm plantations began to change from optimal land to suboptimal land. Soil physical properties are properties related to the shape or original condition of the soil. This study aims to determine the physical properties of soil (texture, porosity, moisture content, soil color, particle density, and bulk density) on peatlands in the tidal area of PT Sinar Gunung Sawit Raya. This research used survey method with descriptive analysis. The soil samples taken were peat soil in the tidal area with purposive random sampling method at a depth of 30 cm. This research was conducted in November 2023 and continued in the laboratory for testing each soil physical properties. The results of the research on soil physical properties at PT Sinar Gunung Sawit Raya on peatlands in tidal areas show that the soil texture is loamy sand, soil porosity is good, moisture content is relatively normal, soil color looks relatively dark, particle density is still low and bulk density value shows low.*

1. INTRODUCTION

Palm oil (*Elaeis guineensis* Jacq) is a plant with a higher vegetable oil content than other oil-producing plants, so palm oil is widely used as the main raw material for refined vegetable oil. Some palm oil is used as a raw material for various derivatives derived from CPO (Crude Palm Oil) or crude palm oil found in palm fruit (Ariyanti *et al*., 2017). Oil palm is usually cultivated and planted on flat land around 15°N - 15°S that is undulating or hilly (slope 0-30%). The optimal rainfall for oil palm plantations is 2000-2500 mm/year, there is no shortage of water and it is evenly distributed throughout the year. Oil palm is a tropical crop so it needs warm temperatures all year round, optimum temperature 24 - 28°C, minimum temperature 18°C, maximum temperature 32°C, humidity 80% and sunlight 5 - 7 hours per day (Haryanti *et al*., 2021). Kebutuhan minyak sawit semakin meningkat setiap tahunnya. Ini mendorong perkebunan kelapa sawit untuk terus meningkatkan luas tanam. Pada tahun 2014, luas areal perkebunan kelapa sawit sekitar 10.9 juta hektar dan minyak sawit mentah (CPO) diproduksi 29.3 juta ton. Luas lahan yang semakin terbatas dan luas lahan yang semakin besar di Indonesia sehingga ruang bagi perusahaan perkebunan untuk memperluas lahan semakin terbatas, sehingga perluasan perkebunan kelapa sawit mulai berubah dari lahan optimal menjadi lahan suboptimal (Darlita *et al*., 2017). Lahan sub optimal adalah lahan marginal dengan kualitas tanah yang relatif buruk. Lahan sub optimal terdiri dari lahan kering asam, lahan iklim kering, lahan rawa pasang surut, lahan rawa lebak dan lahan gambut (Ratmini *et al*., 2018).

Peat soils are formed from the accumulation of organic matter and plant residues over many years. The use of peatland for cultivated crops is still limited by various factors such as peat thickness, high acidity, low fertility, the presence of a pyrite layer, quartz sand substrate (rock weathering) and water system. Despite facing various obstacles, the clearing of peatland for oil palm development continues to increase. This growth is due to the fact that oil palm plantation practitioners are able to overcome or understand various obstacles. Thus making peatland an alternative to oil palm plantation expansion (Soewandita, 2018).

Oil palm plantations were initially made on dry land, but due to the limited dry land, oil palm plantations were developed in wetlands, namely tidal areas (Haris & Septiana, 2020). The tidal zone is an area where the movement of water on the surface of the river is affected by the movement of the moon. Tidal land is found on three major islands, namely Papua, Sumatra and Kalimantan, as well as a small part of Sulawesi and Maluku (Susilawati *et al*., 2017). The growth potential and productivity of oil palm plants in tidal land varies greatly depending on land conditions and the level of management. The results of the experiment of planting oil palm in tidal land with good drainage techniques can produce 25 tons of FFB/ha/year (Winarna *et al*., 2017).

Soil fertility is always related to the physical, chemical and biological properties of the soil that are optimal for plant growth and development. Fertile soil has good physical properties including structure, texture, porosity, soil moisture content (Abdul, 2020). The characteristics of the physical properties of soil must be arranged so that it can be used to determine the physical capacity of soil and soil and water retention (abiotic components). The ability of the physical capacity of the soil is to create drainage, retain water, plasticity, ease of root penetration, aeration and the ability to withstand the potential of plant nutrients (Rauf *et al*., 2020).

Soil physics properties are properties related to the original shape or condition of the soil, including soil structure, soil texture, soil color, soil moisture content, soil temperature, and others. The physical properties of soil are also factors that greatly affect the availability of soil water and air and indirectly affect the availability of plant nutrients. The availability of plant nutrients affects the potential of the soil to produce maximum production. The physical properties of the soil must be considered because these properties can protect the soil especially from damage that can occur during cultivation, some of which include texture, color, moisture content and soil structure. The physical properties of soil differ from place to place. The difference comes from the difference in soil forming factors, namely climate, source material, organism, topography and time (Umin & Anasaga, 2019). This study aims to determine the physical properties of soil (texture, porosity, moisture content, soil color, particle density, and bulk density) in peatlands in tidal areas of PT. Sinar Gunung Sawit Raya.

2. 2. RESEARCH METHODS

2.1. Location and Time of Research

This research was carried out at PT. Sinar Gunung Sawit Raya Manduamas Plantation, Sirandorung District, North Sumatra in November 2023. The sampling coordinate points are as follows:

1. Coordinate points T1 (2.076189 N, 98.277039 E)
2. Coordinate points T2 (2.076168 N, 98.274988 E)
3. Coordinate points T3 (2.072221 N, 98.274957 E)
4. Coordinate points T4 (2.072216 N, 98.276998 E)

Sampling was carried out in Afdeling X (ten) with an area of 10 ha representing block C1 with an area of 32.91 ha. The chemical testing continued at the Central Laboratory of the Faculty of Agriculture, University of North Sumatra.

2.2. Materials and Tools

The material used is peatland in tidal areas, namely intact soil samples and disturbed soil. Then for the analysis material using Sodium Pyrophosphate. The tools used are sample rings, hoes, plastic bags, label paper, meters, pens, camera markers, machetes, knives, digital scales (SF-400C), Erlenmeyer glasses (250 ml), strainers, stirrers (mixers), stop watch, cups, Munsell books, ovens, measuring cups (1000 ml), hydrometers, and thermometers.

2.3. Research Methods

In this study, a survey research method with descriptive analysis is used. Where the samples used were 4 (T1, T2, T3, T4). Then the results of laboratory testing are discussed and conclusions are drawn.

2.3.1 Working Procedure

a. Soil Texture

The soil texture is determined using the Buoyoucos hydrometer method. The measurement was started by weighing 50 g of dry soil. Then it was put in a 250 ml Erlenmeyer glass. Then 10 ml of sodium pyrophosphate solution was added and then shaken until the solution is combined and let stand for 24 h. It was then poured into a measuring cup (1000 ml) and added with aquadest. The sample was shaken 25 times (plus amyl alcohol to remove the foam). Then insert the hydrometer within 45 seconds for a reading of 1. After the next 2 h it was continued for reading 2, and determine the percentage of clay, sand, and dust using the following equations.

$$\text{Clay + Silt} = \frac{\text{First reading}}{\text{Soil Sample Weight}} \times 100\% \tag{1}$$

$$\text{Clay} = \frac{\text{Second reading}}{\text{Soil Sample Weight}} \times 100\% \tag{2}$$

$$\text{Sand} = 100 - \text{Clay} + \text{Silt} \tag{3}$$

$$\text{Silt (\%)} = \text{Eq. (2)} - \text{Eq. (1)} \tag{4}$$

To determine the soil texture, the percentage of clay, silt, and sand were plotted in a triangle of soil texture.

b. Soil Porosity

Porosity is the ratio of the volume of the pore space to the total volume of the soil. This porosity is expressed in percent (%). The porosity of the soil was determined from bulk density (BD) and particle density (PD) based on the following equation:

$$\text{Porosity (\%)} = 1 - \frac{\text{BD}}{\text{PD}} \text{ X } 100\%$$

c. Moisture Content

The step in determining the moisture content was carried out by weighing the air dry sand weight (BTKU) of 10 g and weighing the empty cup used. Then put it in the oven at 100°C for 24 h, then weigh again the soil after heating (BTKO). Moisture content (MC) was calculated as the following:

$$\text{MC (\%, db)} = \frac{\text{BTKU} - \text{BTKO}}{\text{BTKO}} \times 100\% \tag{1}$$

d. Soil Color

The determination of soil color can be directly determined in the field, namely by observing the soil sample, but before determining the soil color, first determine the state of the soil sample, whether it is dry, wet or humid. Then match the soil sample with the Munsell soil color book for more accurate determination.

e. Particle Density

Determination of particle density is carried out by weighing 250 ml measuring cup and fill it with 27 g of oven-dried soil in a fine condition. Then 150 ml of water was added and stirred until the soil wet and on the neck of a clean measuring cup. Then let it sit for 30 min. The volume of groundwater was observed and Pore Space Volume (VRP) was calculated. The Particle Density (PD) value was calculated according to the following formula.

$$\text{PD} = \frac{\text{Soil Weight}}{\text{Soil Volume} - \text{Pore Space Volume}} \text{ g/cm}^3 \tag{2}$$

f. Bulk Density

Bulk density was determined from whole soil taken using a sample ring. Sample of soil within a ring was weighed. The lid of the sample ring was opened, then put paper at the bottom so that the soil did not fall out. Then put it in the oven at 100°C for 24 h. The sample ring and dry soil was reweighed after heating to find the weight of dry soil (BTKO). Soil bulk density (BD) was calculated by dividing soil weight (BTKO) over soil volume (V).

3. RESULTS AND DISCUSSION

3.1. Soil Texture

Soil texture is the relative ratio of the sand fraction, dust fraction, and clay fraction of the soil, which also describes the roughness or fineness of the soil. Each type of soil has its own percentage of sand, silt and clay. There is soil that is dominated by the sand fraction, so the texture is sandy. There are soils that are dominated by the dust fraction, so the texture is dusty. There are also soils that have a clay texture, because these soils are dominated by the clay fraction. There is soil with a sand, dust or clay texture. For example, sandy clay, silty clay, or loamy clay (Abdul, 2020). Based on the results of research conducted at PT. Sinar Gunung Sawit Raya, soil texture conditions at T1, T2, T3, and T4 show that the soil texture is loamy sand (Table 1).

From Table 1, the T1 value is the same as the T2 value, namely for the sand fraction it is 84.56, while for the dust fraction the value is 8.00 and for the clay fraction it is 7.44. Then at T3 the sand fraction value was the same as T4, namely 86.56, but the dust fraction had a different value, namely at T3 it was 4.00 and at T4 it was 6.00. Furthermore, for the clay fraction, the T3 value was 9.44 and for T4 it was 7.44. So a line drawn on the soil texture triangle shows the loamy sand texture. One class of soil texture which is located around the middle of the triangular texture is clay loam. Soil texture of clay loam has a balanced composition between coarse and fine fractions, and clay loam is often considered an ideal texture for agriculture. Umin & Anasaga (2019) said soil with a clay texture of >35% has high levels of nutrients and water storage, and soil with a silty texture is better than soil with a sandy texture.

Table 1. Results of soil texture analysis

No	Soil Samples	Texture – Hydrometer % Fraction			
		Sand	Silt	Clay	Texture
1	T1	84.56	8.00	7.44	Loamy sand
2	T2	84.56	8.00	7.44	Loamy sand
3	T3	86.56	4.00	9.44	Loamy sand
4	T4	86.56	6.00	7.44	Loamy sand

Table 2. Results of soil porosity analysis

No	Soil Samples	Bulk Density (g/cm^3)	Particle Density (g/cm^3)	Porosity %
1	T1	0.43	0.90	53
2	T2	0.52	0.90	43
3	T3	0.36	0.90	60
4	T4	0.30	0.90	67
		Average		**55.75**

3.2. Soil Porosity

Soil porosity is a physical property of soil that is important for knowing the condition of the number of soil pores which has an impact on water availability and air circulation in the soil. Soil porosity is influenced by several factors, namely: structure, organic matter content, soil texture and soil pore size. If organic matter is high, soil porosity will also increase. Soil porosity is high if the soil has a granular or crumbly structure, whereas if the soil has a solid or massive structure it will be inversely proportional, meaning the porosity is low (Afrianti *et al*., 2019).

Based on the analysis results obtained in Table 2, it shows that the soil porosity values for samples T1 (53%), T2 (43%), T3 (60%), and T4 (67%) so that the average value is 55.75% so relatively good. According to Marbun *et al*. (2022), the soil porosity class is said to be good if the porosity value is above 50%. This porosity value is considered good because oil palm roots easily penetrate the soil to find organic material. Apart from that, the soil is able to retain rainwater so that plants do not always lack water (Marbun *et al*., 2022). Then Agus *et al*. (2016) said that high peat soil porosity is generally estimated at 70 - 95%. Peat porosity decreases with continuous drying. The degree to which peat porosity decreases due to drying depends on the level of peat decomposition. The decrease in sapric peat was the largest, followed by hemic peat, and the decrease in fibric peat was the smallest (Agus *et al*., 2016).

3.3. Water content

Groundwater is water that moves through the soil and is found in the pore-forming spaces between soil particles and in rock crevices. Soil water content is tied to the type of soil pores. As previously stated, water in soil will be stored well in soil pores if it contains many micropores.

Table 3. Water content of soil (in % dry basis)

No	Soil Samples	BTKU	BTKO	Water content %
1	T1	10.03	2.39	319
2	T2	10.05	2.12	374
3	T3	10.00	1.84	443
4	T4	10.00	2.10	376
		Average		**378**

Based on the analysis results in Table 3, the water content value was obtained, namely at T1 it was 319%, T2 was 374%, T3 was 443% and T4 experienced a decrease of 376%. So the average value obtained is 378% so it is classified as normal. According to Rismawati (2022), the water content value in peat soil is between 100 and 1,300%. The lack of water content is caused by the low level of canopy closure in oil palm stands, thereby inhibiting oil palm growth. This proves that water content has a direct effect on oil palm vegetative growth in plant tissue and also acts as a solvent for inorganic salts. And if on the contrary, a high percentage of water content can be caused by soil processing. Soil processing can improve plant root surfaces, humidity, aeration, water content in the soil, increase infiltration, and suppress plant disturbances (Marbun *et al*., 2022).

Water content is one of the factors that can influence the physical properties of peat soil. Peat soil has a relatively high capacity to bind or store water based on its dry weight. Generally, the upper peat in the research area is classified as dry peat because it has dried out. The high groundwater level is influenced by the drainage system, so it will have an impact on the level of soil maturity and decomposition (Sitohang, 2022).

3.4. Soil Color

Soil color is a combination of different colors from several components that make up soil. The color of a soil is directly proportional to the overall mixture of colors reflected by the soil surface. Soil color is determined by the specific surface area multiplied by the soil volume fraction (Marbun *et al*., 2022). Based on the analysis results in Table 4, it can be seen that each soil sample has almost the same indicator scale, but there are also differences in the indicator scale in the Munsell Soil Color Book.

Table 4. Soil color analysis results

No	Soil Samples	Soil Color (Munsell)			Remark
		Hue	Value	Chorma	
1	T1	2.5 yellowish red	2.5	1	Reddish black
2	T2	2.5 yellowish red	2.5	1	Reddish black
3	T3	2.5 yellowish red	2.5	2	Very dusky red
4	T4	2.5 yellowish red	2.5	1	Reddish black

In samples T1, T2, and T4, the same results were obtained, namely hue 2.5 YR 2.5/1 with the color Reddish Black. In sample T3, the hue result was 2.5 YR 2.5/2 with the color Very Dusky Red. According to Marbun *et al*. (2022), this soil has a clay texture, feels heavy and smooth, is very sticky, easy to shape like balls, and easy to roll. The red color in this sample indicates a lack of organic matter in the soil. Therefore, it can be interpreted that the deeper the soil, the lower the soil organic matter content. This is different from dark colored soil, where this soil contains high levels of organic matter so it is a good planting medium to use (Marbun *et al*., 2022).

Umin & Anasaga (2019) believes that soil color can also be influenced by the organic material content in the soil. Soil with a high organic matter content of 3.01% is darker in color. On the other hand, if the organic matter content is only 1.0%, the soil color becomes lighter, and if organic matter accumulates, the soil color becomes darker.

3.5. Particle Density

Several factors influence the soil volume weight value, namely soil organic matter content, soil texture, number of soil pores, and plant roots. High levels of organic matter in the soil can reduce the volume weight value of the soil. Soil with more organic material tends to be looser than soil with less organic material. Organic matter increases the number of soil pores thereby reducing soil density. Soil volume weight is influenced by structure (in terms of pore space), soil texture (in terms of particle size and density), and organic matter content (Megayanti *et al*., 2022).

Table 5. Results of particle density analysis

No	Samples	Soil Weight (g)	Soil Volume (ml)	VRP	Particle Density (g/cm³)
1	T1	27	50	20	0.90
2	T2	27	50	20	0.90
3	T3	27	60	30	0.90
4	T4	27	70	40	0.90

Based on the analysis test results in Table 5, the particle density value of 0.90 g/cm³ is in the low category compared to the particle density value that it should be. According to Agus *et al*. (2016), the particle density value of peat soil is 1.4 g/cm³. Particle density is the mass of solid particles per volume of soil. Typically, the density of mineral soil particles is 2.6 g/cm³. Particle density is closely related to mass density. The relationship between particle density and mass density determines the pores of the soil. Particle density is expressed in soil weight (grams per unit volume cm³ of soil). So, if 1 cm³ of solid soil weighs 2.6 g, then the density of the soil particles is 2.6 g/cm³. The organic matter content in the soil has a significant influence on the density of soil particles. The more organic material in the soil, the smaller the particle density value. As a result, the density of the top soil particles is lower than the density of the soil particles below. The presence of organic material reduces the particle density value (Afrianti *et al*., 2019).

3.6. Bulk Density

Soil specific gravity (bulk density) is an indication of soil density where soil density is influenced by its level of maturity. This soil density can make it difficult for plant roots and water to penetrate the soil. To reduce soil density, you can apply organic fertilizer. Mass density is also a bulk density which shows the ratio between the volume of soil pores and the dry weight of the soil. The bulk density value will be higher if the soil is denser, meaning it is more difficult for plant roots to penetrate. This is different from land that has never been cultivated. The unit weight value is influenced by soil processing factors.

The results (Table 6) show that the bulk density values for each sample are different. At T1 it is 0.43 g/cm³, T2 is 0.52 g/cm³, T3 is 0.36 g/cm³ and at T4 it is 0.30 g/cm³, an average value of 0.40 g/cm³ is obtained, so it is categorized as low. According to Maysarah *et al*. (2021), in general the bulk density value of peat soil is between 1.1 g/cm³ and 1.6 g/cm³. Furthermore, Sitohang (2022) also said that the bulk density value of peat soil ranges from 1.2-1.8 g/cm³. The specific gravity value of peat is mainly determined by the maturity of the peat soil (Sitohang, 2022). A low specific gravity value will affect the penetration of plant roots into the peat soil layer. However, root penetration is limited by standing water in the peat and soil acidity, and low root density also affects their strength, this causes the roots in the soil to not be strong enough to hold the plant stem (Maysarah *et al*., 2021).

Table 6. Bulk density analysis results

No	Soil Sample	Soil Volume	BTKO (gram)	Bulk Density (g/cm³)
1	T1	90.51	38.99	0.43
2	T2	90.51	47.85	0.52
3	T3	90.51	32.63	0.36
4	T4	90.51	27.45	0.30
		Average		**0.40**

The low value of soil bulk density is caused by the soil structure being very strong and having moderate macro pores, as well as the activity of soil microorganisms increasing so that the bulk density value does not change much (Marbun *et al*., 2022). And this has nothing to do with sample extraction. Soil with a high organic content also has a lower bulk density. Low soil density values facilitate soil management and can influence plant growth. Soil with a high bulk density value is usually more difficult to cultivate than soil with a lower bulk density value. This is because the land conditions are not too saturated with water and support the reproductive activity of soil organisms so that they can speed up the decay process. The more microorganisms there are in the soil, the rate of the decomposition process will increase, and the more the decomposition process, the specific gravity value will increase (Marbun *et al*., 2022).

Based on the level of decomposition, there are three types of decomposition of organic matter in peat soil; fibric, hemic, and sapric. Fibric is a peat material with a low decomposition rate, usually having a bulk density of <0.1 g/cm³. Hemic is a peat material with a moderate level of decomposition and a specific gravity of 0.1 to 0.2 g/cm³. Saprik is the most mature peat material with a high specific gravity of more than 0.2 g/cm³ (Soewandita, 2018). Furthermore, soil that has a specific gravity value of <2 g/cm³ of soil can support the reproductive activities of soil organisms and encourage the decomposition process (Marbun *et al*., 2022). Furthermore, it is said that soil with a specific gravity of 0.9 to 1.2 g/cm³ has a strong clay structure. The relatively stable structure has moderate macropores, which means the density is also moderate (Marbun *et al*., 2022). Excessive drying of peat will damage peat colloids. If the dry season lasts long, the swamp will become permanently dry (permanent drying) and the peat will become like charcoal so that it is unable to absorb nutrients or store water (Lumbantoruan *et al*., 2021).

4. CONCLUSIONS

Based on the physical properties of the soil, the results of the research and the discussion description, it can be concluded that the soil texture at PT. Sinar Gunung Sawit Raya is loamy sand, soil porosity is good, water content is relatively normal, soil color looks relatively dark, particle density is still low and the bulk density value is low.

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