International Journal of Agricultural Technology 2025 Vol. 21(5):1805-1816
DOI: https://doi.org/10.63369/ijat.2025.21.5.1805-1816
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Comparison of permeable and water holding capacity between flat and steep soils

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Hermawan, B., Novela, D. E., Putri, E. L. and Utami, W. A. (2025). Comparison of permeable and water holding capacity between flat and steep soils. International Journal of Agricultural Technology 21(5):1805-1816.

Abstract Permeability and water holding capacity are changes in land use type can lead to variations in soil water characteristics. Both soil characteristics are strongly related with other solusion such as the bulk density, soil porosity, and particle size characterized. Results showed that the soil porosity and soil holding capacity was higher at the flat than in the steeper sites, and there was not significantly differed between the latter two sites, the trend of porosity was similar to the holding capacity. From flat to steep lands, the soil physical properties in the 0-10 cm soil layer partially improved, bulk density, soil porosity and texture were significantly higher at the flat than at the steep sites. Soil texture, porosity and bulk density were found to be the key factors affecting soil porosity and water holding capacity. The results provided insight into the effects of vegetation restoration on local hydrological resources and can inform soil water management and land use planning on the regional.

Keywords: Flat soil, Permeability, Steep soil, Water holding capacity

Introduction

Palm oil is one of the most abundant vegetable oil crops produced and consumed throughout the world. The oil production is very efficient and stable and can be used in a variety of food and cosmetic applications, and used as raw material for fuel and biodiesel. Palm oil has several advantages compared to oil-producing plants other vegetables, such as high yields per hectare, long economic life, high adaptability to environmental conditions, as well as the ability processed and utilized widely, both in the food and non-food sectors (Ginting and Afrianti, 2021).

Oil palm plantations are spread across 26 provinces in Indonesia, covering all of Indonesia's provinces in Sumatra and Kalimantan, as well as several provinces such as West Java, Banten, Central Sulawesi, South Sulawesi, West Sulawesi, Gorontalo, Maluku, North Maluku, Papua and West Papua. Riau

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Province will remain a producer of the largest oil palm plantation in 2022, with a plantation area of 2.87 million hectares or around 18.70% of the total area of oil palm plantations. Private plantations own around 8.58 million hectares of oil palm land, or 56% of the total. People's plantations control 6.21 million hectares, or 40.51%. Meanwhile, large plantations owned by the state only have around 0.55 million hectares, or 3.57% (Central Statistics Agency, 2023).

Smallholder oil palm plantations are part of the chain palm oil businesses and required to implement sustainability principles. Certification sustainability is now mandatory to enter the market, meanwhile, the lack of plantation management capacity is an obstacle for farmers. Because economic interests still dominate people's oil palm plantations, then it is not easy to fulfill sustainability principles in smallholder oil palm plantations. However, this is not used as an excuse by policymakers as also not to realize sustainable smallholder oil palm plantations (Saragih *et al.,* 2020). Meeting the water needs of oil palm plants with management water can be one of the elements that can help realize the sustainability of oil palm plantations.

Sloping land is more vulnerable to soil damage due to erosion, which can result in a reduction in organic matter content and reduced nutrients and water available to the plant. Topography, including slope, plays an important role in soil formation, with differences in slope causing differences in depth and clear characteristics of the soil, especially in its physical properties. Physical properties of soil have a major impact on the availability of water, air, and plant nutrients, which in turn affects the land's overall production potential. To achieve maximum production, oil palm cultivation must be supported by conditions optimal environment. This increase in production is influenced by interaction between internal plant factors (genetics) and external factors (environment). Environmental factors influence production levels, growth, and development of oil palm plantations (Melta, 2021).

This research aimed to identify the relationship between permeability soil with several physical properties at five levels of slope of oil palm land.

Materials and methods

This research is located on a community plantation with an area of 15 ha in Talang Tengah I Village is in the administrative area of Pondok District Kubang, which is located in Central Bengkulu Regency, Bengkulu Province. This stage was included pre-research data collection activities. In the form of literature study data that made location maps for sampling. The research location map was based on an administrative map of the people's oil palm plantations, and a slope map covering five slope classes.

Pre-survey activities were carried out by observing field conditions directly, determined the slope of the land and the boundaries of the research location. The obtained information was used as supporting material in determining sample points on the research location map.

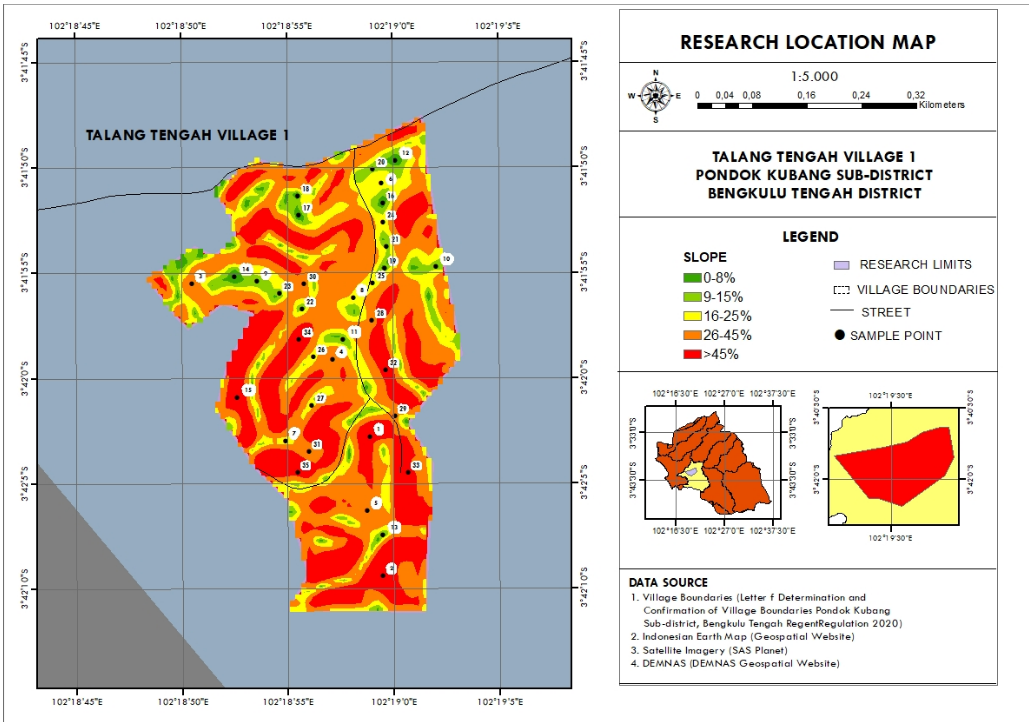

Figure 1. Research location map

Soil samples from each slope were collected and then undergone a series of analyses according to the observed research variables. Various soil physical property variables analyzed were recorded soil permeability, porosity, unit weight, soil texture, organic carbon, and moisture content.

Data analysis was carried out using a correlation approach. In this research, the correlation test is used to determine whether there is a relationship between the dependent variable and the dependent variable. Soil permeability with various other physical properties (total pore space, volume weight, soil texture, water content, and C-organic) based on different slope classes. Apart from that, analysis was measured the extent of the relationship between the variables studied. The correlation coefficient interpretation is presented in Table 1.

Table 1. Correlation coefficient and its Interpretation

Correlation coefision	Interpretation of correlation coefficients
0.00	No correlation
0.01 – 0.20	The relationship is very weak
0.21 – 0.40	Weak correlation
0.41 – 0.70	Moderate correlation
0.71 – 0.99	High correlation
1.00	Perfect correlation

*source : Rahmawati *et al.* (2024)

Results

General description of research area

This research is located in Talang Tengah 1 Village, Pondok Kubang District, in Central Bengkulu Regency. The geographical location of Central Bengkulu is at 3° 12′ 24.44″ (South Latitude) and 102° 7′ 34.18″ (East Longitude). Administratively, the Central Bengkulu Regency has various regional boundaries. To the north, this district borders North Bengkulu Regency and Rejang Lebong Regency; to the east, it borders Kepahiyang Regency; to the south, it borders Seluma Regency and Bengkulu City; to the west, this district borders directly on the Indonesian Ocean. Central Bengkulu Regency is located at an altitude of 0 to 541 meters above sea level and has a sporadic distribution, so the topography of the area tends to be wavy and hilly.

Oil palm plants in this area are planted on various slopes, ranging from flat to hilly. Including slopes with gradients of 0-8% (flat), 8-15% (gentle), 15-25% (quite steep), 25-45% (steep), and more than 45% (very steep). The varying slopes can be seen in Figure 2.

Relationship between several physical properties of soil and permeability volume weight

The results of the bulk density analysis are shown in Figure 3. The graph showed a linear relationship between slope class and soil volume weight. The resulting regression line equation was $y = 0.025x + 0.939$, which showed that every one unit increased in slope class which increased to 0.025 in volume weight. The coefficient of determination value $R^2 = 0.8311$ showed 83.11% of the variation in volume weight can be explained by the slope class. There was a positive relationship between slope class and volume weight, where increased in slope class which tended to increase in volume weight.

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Figure 2. Oil palm land based on five slope classes: (a) flat, (b) ramps, (c) rather steep, (d) steep), (e) very steep

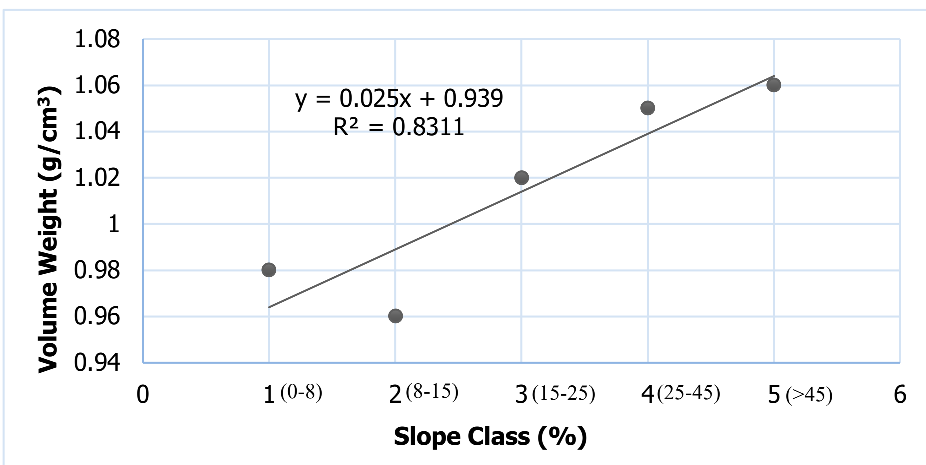

Figure 3. Relationship curve between slope class and volume weight

Total pore space

Loose soil pores indicated the ability of the soil to allow water and air to enter more easily, so that roots can penetrate more easily. It showed the relationship between slope class and total pore space. The resulting linear regression equation is y = −1.66x + 53, with a coefficient of determination R^2 = 0.9115 (Figure 4). It showed that 91.15% of the variation in total pore space can be explained by variations in slope class. From the graph, it can be seen that the steeper the slope class, the total pore space decreased. In addition, the higher the organic matter content and stability of soil aggregates, the lower the bulk density value were shown. This decreased in bulk density contributes to increase in the total pore space in the soil. Overall, the combination of a high proportion of sand and abundant organic matter content created soil conditions with optimal porosity for water and air movement.

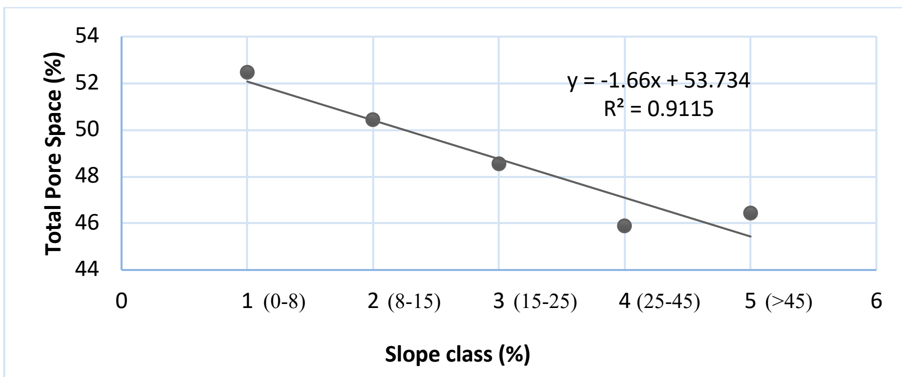

Figure 4. Relationship curve between slope class and total pore space

Soil texture

Testing of these physical properties of soil texture conducted in the laboratory was used the hydrometer method. Variations in proportion of sand, silt, and clay determine the type of soil texture at each location. The results of the texture analysis are shown in Figure 5.

The graph showed the relationship between slope class and the percentage of soil texture in the form of sand, clay, and silt. The percentage of sand decreased along with the increased in slope class, with the regression equation y was −3.676x+60.534 and the R^2 value was 0.8781. It showed that 87.81% of the variation in the percentage of sand which changed in slope class. Meanwhile, the percentage of clay increased slope class, with the regression equation y was 2.637x+24.827 and the R^2 value was 0.614. The 61.4% of the variation in the percentage of clay is changed in slope class.

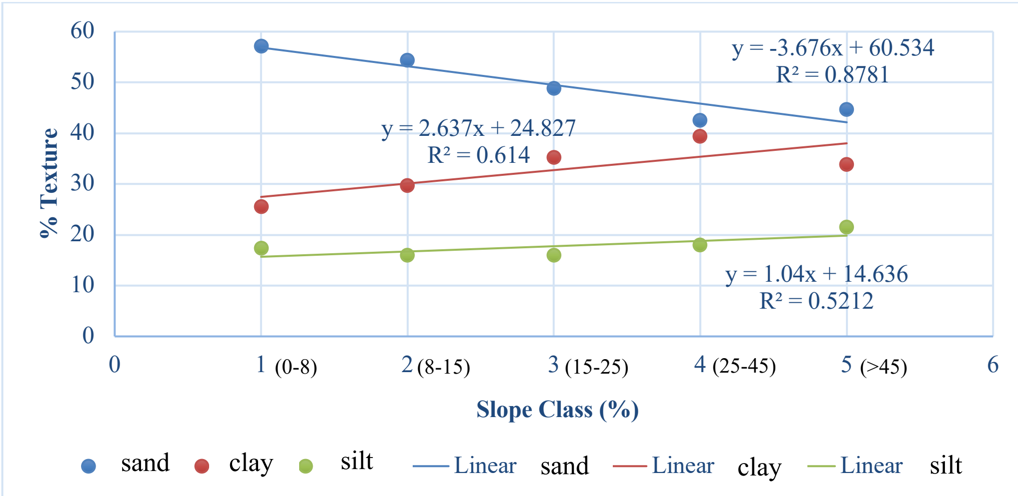

Figure 5. Relationship curve between slope class and soil texture

Gravimetric water level

The results of the water content analysis are shown in Figure 6. The graph showed the relationship between Slope Class and Water Content. From the data, it showed the higher slope class after measured water content. The resulting regression line equation was $y = 1.305x + 3.151$, with an R^2 value of 0.8741. This R^2 value showed that 87.41% of the variation in water content can be explained by variations in slope class.

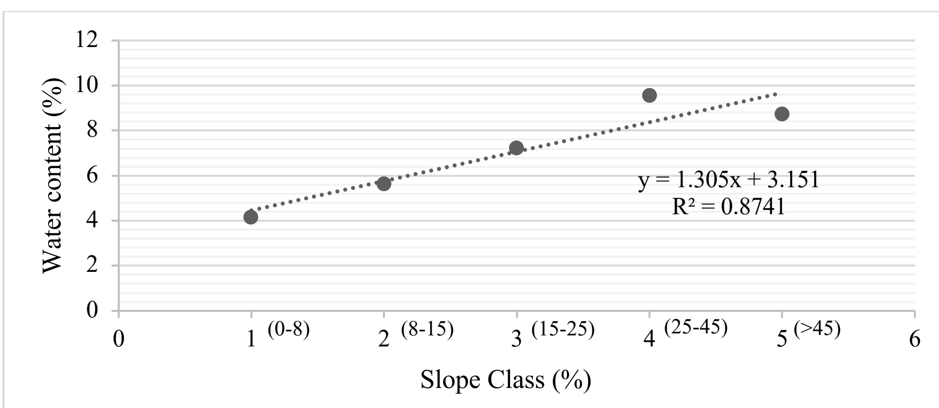

Figure 6. Relationshipcurve between slope class and water content

Organic carbon

The results of the organic C analysis are shown in Figure 7. Soil carbon sampling involves collecting soil samples to measure the amount of carbon stored in the soil. This is crucial for understanding soil health, tracking carbon sequestration, and participating in carbon offset programs.The process includes determining sampling locations, depth, and frequency, as well as employing appropriate laboratory testing methods.

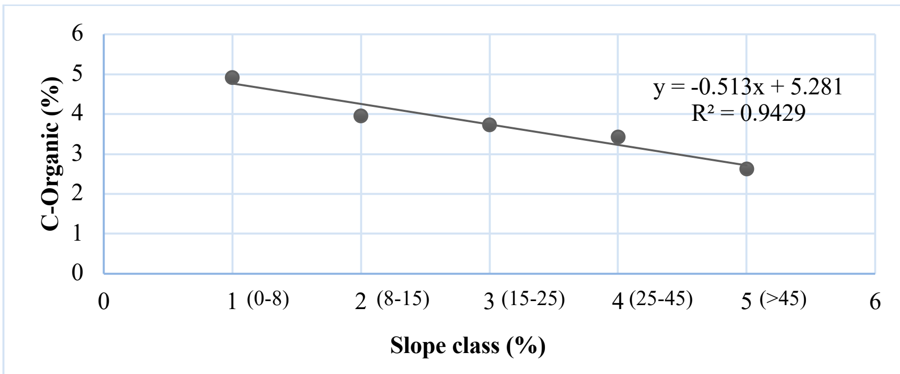

Figure 7. Relationship curve between slope class and C-organic

The graph above showed the relationship between slope class and C-organic content. I can be seen that organic carbon content decreased which increased in slope class. The resulting regression line equation was $y = -0.513x + 5.281$, with a coefficient of determination value of $R^2 = 0.9429$. The R^2 value indicated that 94.29% of the variation in organic carbon content explained by variations in slope class. The negative value in the equation above indicated an inverse relationship where an increase in slope class is followed by a significant decrease in C-organic carbon content.

Relationship between different slopes and permeability

The results of the permeability analysis are shown in Figure 8. Soil permeability is the ability of soil to transmit water and air. It's a measure of how easily fluids can pass through a soil's interconnected pore spaces. This property is crucial for various applications, including agriculture, construction, and water management.

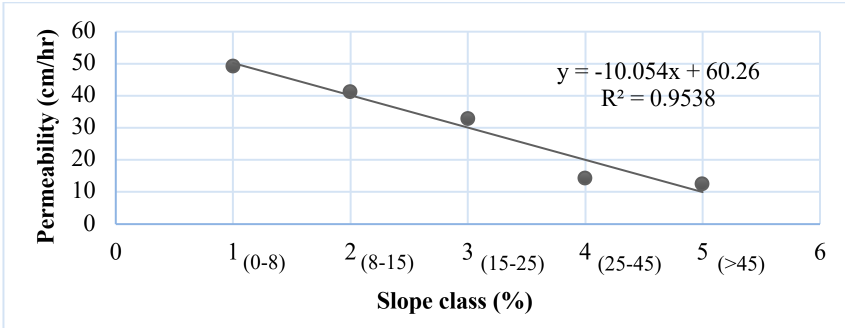

Figure 8. Slope class and permeability relationship curve

The graph above showed the relationship between slope class and permeability. The permeability decreased as the slope class increased. The resulting regression line was the equation $y = -10.054x+60.26$ with a coefficient of determination $R^2 = 0.9538$. The R^2 value showed that 95.38% of the variation in permeability which showed the variations in slope class. Increasing slope class is associated with a significant decrease in permeability.

Discussion

The results of the Pearson correlation analysis showed that there was a highly correlated negative relationship between volume weight and soil permeability, with a Pearson correlation value of -0.944. When the volume weight increased, soil permeability decreased. These results indicated that the heavier the soil volume, the lower the soil ability to absorb water. According to Sari *et al.* (2020) who stated that soil with low organic matter content usually has a higher specific gravity. Conversely, soil with a lower specific gravity allows water to penetrate soil pores more easily, increasing the fertilization process, and increasing the utilization of oxygen in the soil.

The results of the Pearson correlation analysis showed that there was a high correlation between total pore space and soil permeability with a correlation coefficient of 0.981. There was a positive relationship between these two variables which increased in total pore space correlating with an increase in soil permeability. This is in accordance with Margolang *et al.* (2015) in Lesmana *et al.* (2023) where soil permeability is influenced by the overall pore area of the soil, so it can be said to be quite good. The higher the total pore space in the soil, the faster the rate of water movement through the pores. Therefore, soil with a high total pore space tends to be better permeability.

Soil that contains more sand fractions tends to make it easier for plant roots to penetrate. However, this type of soil also becomes more porous, which means that water passes through it more easily, and as a result, the availability of nutrients in the soil becomes low. Conversely, if the soil is dominated by clay fractions, plant roots will have difficulty penetrating, but this type of soil becomes less porous, so water does not easily pass through (Syofiani *et al.*, 2020). Rahmawati *et al.* (2024) said that dust has difficulty forming solid soil aggregates because its particles are very small, making it susceptible to being carried away by strong surface flows such as heavy rain or fast surface water flows.

The ability of soil to retain water is greatly influenced by its texture. Coarse-textured soil has a lower water-holding capacity compared to fine-textured soil. As a result, plants are grown in coarse-textured soil usually dry out faster than plants grown in clay or loamy soil, which can retain water more effectively (Umin and Anasaga, 2019) .

The results of the Pearson correlation analysis showed a high negative relationship between slope class and permeability. The correlation value was found to be -0.977 with a significance value of 0.004. This negative correlation increased in slope class tended to decreased in permeability. The results of the study by Suryani *et al.* (2022) stated that soil porosity and permeability tend to decrease along with the height of the land slope. The decreasing in permeability is caused by the presence of vegetation and litter layers covering the soil surface, as well as the activity of soil microorganisms, especially bacteria. These microorganisms play a role in decomposing organic matter, maintaining soil aggregate stability, and maintaining soil pore structure. Soil that can easily transmit water is called *permeable*, while soil that is unable to transmit water is called impermeable *because* it has very limited water flow capacity. The pore space between soil particles that is not filled by other mineral materials facilitates the filling and flow of water in the soil, which is reflected in the rate of soil permeability. The more pores in the soil aggregate, the higher the porosity, and the higher the soil's ability to drain water (Ayuningtyas, 2023).

Based on results at different slopes on oil palm land, it obtained permeability showed a high correlation relationship and a positive relationship direction with the sand fraction, total pore space, and C-organic. Permeability is shown to be a high correlation and a negative relationship direction with volume weight, water content, and clay fraction. While the relationship between permeability and dust fraction was not significantly related.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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(Received: 29 September 2024, Revised: 30 May 2025, Accepted: 9 July 2025)