Available at : https://ejournal.unib.ac.id/index.php/terrajournal ISSN 2621-0207
DOI : https://doi.org/10.31186/terra.7.2.110-115

TERRA
Journal of Land Restoration

# Groundwater Retention Based on Toposequence in People's Oil Palm Plantations

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## ABSTRACT

*Soil, water, and crops are interdependent components of agricultural systems, and understanding their characteristics and interactions is critical for effective agricultural management. This study investigates the relationship between soil water-holding capacity and varying land slope gradients. The research was conducted on a community oil palm plantation in Talang Tengah I Village, Pondok Kubang District, Central Bengkulu Regency. A purposive sampling method was applied at five slope categories: flat (0–8%), sloping (8–15%), moderately steep (15–25%), steep (25–45%), and very steep (45–100%). Data analysis was performed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with WarpPLS 7.0 software. The findings demonstrate a significant influence of slope on soil water-holding capacity. Increasing slope gradients are associated with reduced soil permeability, increased bulk density, decreased total pore space, and lower soil organic carbon content, collectively leading to diminished water-holding capacity. The developed model accurately represents the relationships between variables, indicating that slope directly affects organic matter, sand content, and permeability, while bulk density impacts total pore space and permeability, which in turn influence water-holding capacity. The results emphasize the importance of considering land slope in soil and water management strategies to optimize agricultural productivity. Future applications of this model could guide sustainable land-use planning and inform erosion control measures to maintain soil quality and water availability in sloped agricultural landscapes*

*Keywords:* *relationship model, slope, water holding capacity*

## INTRODUCTION

Soil, water, and plants represent fundamental components of an interconnected system that governs plant growth and productivity. A comprehensive understanding of these three elements, including their individual characteristics and interrelationships, is crucial for optimizing agricultural management systems. Soil functions primarily as a medium for plant growth and structural support, providing a foundation for nutrient exchange and root development (Hou *et al*., 2020). Water plays a vital supportive role, enabling physiological processes essential for plant growth and development. One key aspect of water in agricultural systems is its presence as groundwater—water located below the soil surface in saturated zones where all pores are filled with water (Adrinal *et al*., 2024; Putri *et al*., 2023). Groundwater forms as rainwater or other surface sources infiltrate the soil, seeping into pores between soil particles and rocks through the infiltration process (Qing *et al*., 2020). The availability of groundwater directly impacts plant growth and productivity (Glanville *et al*., 2023).

Adequate water supply during the initial stages of plant development is a critical, non-negotiable requirement for successful cultivation (Robbins & Dinneny, 2017). Water requirements vary significantly depending on the type of crop, with oil palm (*Elaeis guineensis*) being among the most water-intensive plantation crops. Oil palm cultivation demands annual rainfall ranging from 1,750 to 2,000 mm, evenly distributed throughout the year, to support its growth and yield potential (Harahap *et al*., 2021). The plant's fibrous root system makes it particularly susceptible to drought stress, as it relies on the water present in the soil's pore spaces within the root zone. Reduced soil moisture content increases soil penetration resistance, hindering root growth and subsequently affecting overall plant development and productivity (Gavrilescu, 2021).

The capacity of soil to store and retain water, commonly referred to as field capacity, is a critical determinant of water availability for plants. Field capacity represents the maximum amount of water the soil can hold after gravitational drainage ceases. This property is influenced by the soil's physical characteristics, such as texture, permeability, bulk density, total pore space, and organic matter content (Phogat *et al*., 2015). These factors collectively govern the soil's water-holding capacity, which directly impacts plant growth, particularly in water-demanding crops like oil palm (Siringoringo *et al*., 2023).

The physical properties of soil, including its texture and structure, play a pivotal role in determining water retention and nutrient availability. Furthermore, the topographical features of the land, especially slope gradients, significantly affect water distribution and retention. Steeper slopes tend to exhibit reduced water infiltration and retention, thereby limiting the soil's capacity to provide adequate moisture to plants (Florinsky, 2016; Hermawan, 2004). Understanding these dynamics is particularly relevant for oil palm cultivation, where optimizing soil and water management is critical for maximizing productivity.

This study aims to examine and develop a model that elucidates the relationship between soil water-holding capacity and varying land slope gradients. By exploring the interplay of physical soil properties and topographical factors, the research seeks to provide insights into optimizing water use in oil palm plantations, ultimately contributing to more sustainable agricultural practices.

## MATERIALS AND METHODS

The implementation of the research consists of a two-time series, which will be carried out in August 2023 to coincide with the flagship research activities chaired by Prof. Ir. Bandi Hermawan, M.Sc., Ph.D, and then continued from March to June 2024. The research was carried out on a 15-hectare community oil palm plantation, precisely in Talang Tengah I Village, Pondok Kubang District, Central Bengkulu Regency, Bengkulu Province. Soil sample analysis was carried out at the Soil Science Laboratory, Faculty of Agriculture, University of Bengkulu.

The tools used in this study are GPS (Global Positioning System), Avenza map application, sample ring, clinometer, soil drill, field knife, plastic, marker, mobile phone, permeameter, oven, analytical balance, hydrometer, and cylinder tube. Meanwhile, the materials used in this study are intact soil samples and disturbed soil, as well as 5% Calgon solution.

The method used in the study is a survey method with sampling on several different slopes *purposive sampling* with the same type of land use (oil palm plantations) and soil types (Ultisols). Soil analysis in the laboratory to study the results of soil water holding capacity analysis and is related to several soil physical properties on various different slopes, namely on flat land (0-8%), sloping (8-15%), slightly steep (15-25%), steep (25-45%) and very steep (45-100%). Seven samples were taken for each slope, so there were 35 soil samples. The research variables and methods are a) soil water retention ability, b) permeability, c) volume weight, d) total pore space, all four using the gravimetric method, e) soil texture method *hydrometer,* and, f) C-Organic method *Walkey and Black.* The laboratory data was then analyzed quantitatively using the PLS-SEM method *(Partial Least Squares Structural Equation Modelling)* using Warp-PLS 7.0 software.

This method aims to determine the relationship between a dependent variable and an independent variable. Results Khodijah & Soemarno (2019), showing that there is a relationship between the total pore space, the weight of soil volume, and the capacity of the soil to hold water. Then research Yulina *et al.* (2015), showing that there is a relationship between slope slope soil permeability and soil texture. Based on the results of research by Khodijah & Soemarno (2019), and Yulina *et al*. (2015), then a conceptual model was built of the relationship between soil capacity to hold water with slope and some physical characteristics of soil.

## RESULTS AND DISCUSSION

The soil capacity to hold water decreases as the slope increases, from 38.78% on flat slopes to 21.72% on very steep slopes (Figure 1). This decline is related to the slope of the slope that affects the movement of water on the surface (*runoff*) (Gusmini *et al*., 2021;

Putri, 2021). On steep slopes, water tends to flow vertically and laterally parallel to the direction of the soil surface and moves down following the contours of the soil, resulting in greater surface flow, while on flat slopes, water moves more vertically, thus increasing water absorption into the soil (Kalembiro *et al*., 2018). Steeper slopes result in greater surface flow, while on flatter surfaces, surface flows tend to be smaller. Steep slopes often undergo more intensive erosion, which can remove the topsoil layers that contain a lot of organic matter. Organic matter is very important in increasing the capacity to hold groundwater. This is in line with Siregar (2023) which states that organic matter plays an important role in increasing groundwater absorption. When the soil is enriched with organic matter, its ability to hold and store water increases significantly. compared to soil with minimal organic matter.

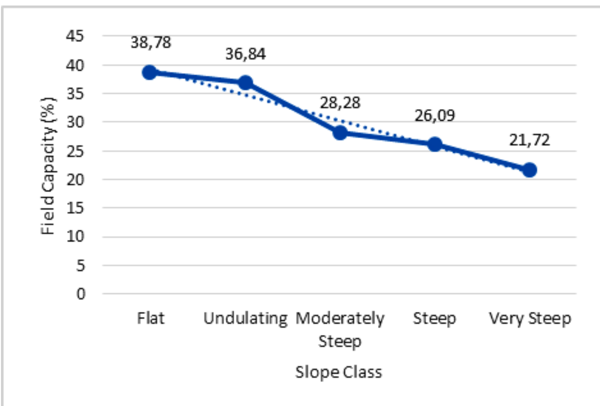


Figure 1. The curve of the relationship between slope level and soil capacity to hold water in smallholder oil palm plantations in Bengkulu Tengah

Soil permeability or K-sat is the ability of soil to drain water in saturated soil conditions. This shows how easily water can seep into the soil. Soil permeability is important because it affects how quickly rainwater is absorbed by the soil, affecting plant growth. The average results of the analysis of soil permeability properties in five slope classes have permeability values that indicate a decrease in the permeability value, along with the increase of slope. On flat soils, permeability was recorded at 42.15 cm/hour, while on very steep slopes, this value decreased to 17.25 cm/hour. This has to do with the varying soil texture at different slope levels which affects how well the soil can absorb and pass water. Sand-dominated soils have larger pores compared to clay-dominated soils. As a result, water seeps more easily through sandy soils (Siringoringo *et al.,*2023).

Bulk Density (BD) is a parameter that indicates the level of soil density or indicates how much soil mass is contained in a given volume. The volume weight at each slope level shows an increasing tendency as the slope increases, from 1.07 g/cm³ on flat soils to 1.21 g/cm³ on very steep soils. This indicates that soils in steeper areas tend to be more dense, This is related to the condition of the layers of *topsoil* which generally has high organic matter on steep land and is more susceptible to erosion than on relatively flat land. According to (Andrian *et al.,* 2014), the length and steepness of the slope are directly proportional to the erosion potential. This is due to the increased surface flow rate *(runoff)* on longer, steeper slopes, which results in more intensive soil erosion. Another cause is that the weight of soil volume is influenced by four main factors that are interrelated. The content of organic matter tends to lower BD by increasing porosity. The texture of the soil, which includes the composition of sand, dust, and clay, affects the density of the soil. The number and distribution of soil pores contribute directly to the empty space in the soil, thus affecting BD. The root system of plants also plays a role in shaping the soil structure and creating channels, which can lower the BD (Megayanti *et al.,* 2022).

Total Pore Space is the sum of all pores, both macro and micropores in the soil. The magnitude of the total value of soil pore space indicates the level of looseness of soil expressed in percent. In the TPS measurement, the average percentage of total pore space showed a slight decrease with the increase in slope, from 59.37% on flat soil to 54.33% on soil on very steep slopes. Fewer pore spaces can indicate a decrease in the soil's capacity to store air and water, which can affect root growth and the activity of microorganisms in the soil. From the data, it can be seen that the TPS value is inversely proportional to BD.

The results of soil texture analysis revealed that there were variations in soil texture composition at the research site. At different levels of the slope, there are fluctuations in the values of sand, dust, and clay fractions. In the steep slope class, there is a decrease in the sand fraction followed by an increase in the dust and clay fraction. This phenomenon can be explained as a result of the erosion process. Erosion that occurs on steep slopes erodes the upper soil layer, which is generally richer in sand fractions. However, the structure of these sandy soils tends to be unstable because the particles are less attached. As a result, this type of soil is more susceptible to

Table 1. The average value of the analysis of soil water holding capacity and some soil physical characteristics on different slopes in the Bengkulu Tengah oil palm plantation with 35 observation samples in the laboratory

| Slope class (%) | Field capacity (%) | K-sat (cm/ hour) | Bulk density (g/cm3) | Total pore space (%) | Land fraction (%) | | | Texture | C-Organic (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sand | Silt | Clay | | |
| Flat to gentle undulating (0-8%) | 38.78 | 42.15 | 1.07 | 59.37 | 55.6 | 21.2 | 23.1 | SCL | 4.93 |
| Undulating (8-15%) | 36.84 | 20.93 | 1.11 | 58.16 | 54.6 | 17 | 28.4 | SCL | 3.97 |
| Moderately steep (15-25%) | 28.28 | 31.13 | 1.15 | 56.84 | 44.2 | 25.3 | 30.5 | SL | 3.74 |
| Steep (25-45%) | 26.09 | 14.45 | 1.14 | 56.95 | 39.8 | 28.1 | 32.1 | SL | 3.44 |
| Very steep (45-100%) | 21.72 | 17.25 | 1.21 | 54.33 | 44 | 24.7 | 31.3 | SL | 2.63 |

Note: SCL= sandy clay loam. SL = sandy loam

erosion. At the same time, this tendency to increase the clay and dust content occurs because the erosion process has brought the upper soil layer so that what remains is that the soil surface is closer to the argillic horizon. The argillic-like horizon itself is the main feature of ultisol soils.

The content of soil organic matter indicates the level of fertility and soil quality. The higher the organic matter content, the better the soil's ability to store water, provide nutrients for plants, and support the activity of beneficial microorganisms. Based on the data, a clear downward trend can be seen in the percentage of soil organic matter along with the increase in slope from flat to very steep.

Data shows that soil on flat slopes has the highest organic matter content of 4.93%. This percentage gradually decreases in the category of steeper slopes, with a value of 3.97% for slopes, 3.74% for slightly steep slopes, 3.44% for steep slopes, and finally reaches a low of 2.63% on very steep slopes. This decrease indicates a negative correlation between the steepness of the slope and the content of soil organic matter.This phenomenon can be explained by several factors, such as more intensive erosion on steeper slopes so that the organic matter content tends to erode more compared to flatter slopes (Refliaty & Marpaung, 2010).

# CONCLUSION

This study concludes that land slope significantly influences various physical characteristics of soil and its capacity to retain water. As the slope becomes steeper, there is a notable decrease in soil permeability, total pore space, and organic carbon content, as well as in the percentage of sand in the soil. Conversely, steeper slopes are associated with an increase in soil bulk density and the proportion of clay and silt particles. These changes collectively result in a reduced water-holding capacity of the soil on steeper slopes. The findings underscore the critical role of slope management in optimizing soil water retention for sustainable agricultural practices.Land-use planning in sloped areas should prioritize soil conservation techniques, such as terracing, contour plowing,and cover cropping, to minimize erosion and enhance soil structure. Additionally, incorporating organic matter into the soil can improve its physical properties and water-holding capacity. These strategies are particularly vital for crops like oil palm, which have high water requirements and are sensitive to drought stress.The results of this study provide a basis for developing slope-specific soil and water management practices to enhance agricultural productivity and sustainability in sloped terrains.

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